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Monsanto Research Corp, Dayton, OH

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Open Mining of Coal

State of the Art

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16. ABSTRACT

This report describes a study of atmospheric emissions from the open mining of coal. The potential environmental effect of this emission source was evaluated using source severity, defined as the ratio of the maximum ground-level concentration of a pollutant at a representative plant boundary to a hazard factor. The hazard factor is the ambient air quality standard for criteria pollutants and an adjusted threshold limit value for other pollutants. Respirable dusts are generated from five unit operations and from wind erosion; contributions from these sources to the total dust loading are: coal transport and unloading, 40%; blasting, 30%; coal loading, 14%; drilling, 12%; coal augering, 1%; and wind erosion, 3%. Emission factors for the unit operations indicate that 13 g of respirable dust are emitted per metric ton of coal mined. Total dust severity is 0.036, and overburden dust severity is 0.014.

Control technology in open coal mining has been implemented for drill rigs, haul roads, and coal refuse piles. The industry is experiencing a high growth rate (3.5% per year), and the growth factor for the industry (1978 emissions/1972 emissions) is 1.23.

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by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from the open mining of coal. This study was conducted to provide a better understanding of the distribution and characteristics of emissions from this industry. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility, as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether emissions reduction is necessary for specific industries.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies, and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This State-of-the-Art Report contains data on air emissions from the open mining of coal. This study was completed for the Extraction Technology Branch of the Resource Extraction and Handling Division, IERL-Cincinnati. Mr. John F. Martin served as EPA Project Leader.

ABSTRACT

This report describes a study of air pollutants emitted from the open mining of coal. The potential environmental effect of the source was evaluated using source severity values (source severity is the ratio of the maximum time-averaged ground level concentration of an emission to its hazard factor).

Open coal mining is a major method of mining coal in the United States. Approximately one-half of the 546×10^6 metric tons of the raw coal produced in 1972 was mined by open mining methods (strip and auger). The representative source was defined in this study as a mine producing 108×10^3 metric tons of raw coal per year and having an area of 2.0 km^2. The representative mine has a life expectancy of 20 years, a stripping ratio of 13.6 m overburden/m coal, an annual land disturbance of 98.5×10^3 m^2, and is located in the Midwest (Illinois or Indiana).

Respirable dusts, the only hazardous emissions, are generated from five unit operations and from wind erosion; the contributions from these sources to the total dust loading are: coal transport and unloading, 40%; blasting, 30%; coal loading, 14%; drilling, 12%; coal augering, 1%; and wind erosion, 3%. The respirable particulate (<7 μm) for the open coal mining industry in 1972 amounted to 3,600 metric tons. The emission factors for the unit operations indicate that 13 g of respirable dust are emitted per metric ton of coal mined. The total dust severity from the representative source is 1.0×10^{-3}, the coal dust severity is 0.036, and the overburden dust severity is 0.014.

Control technology in open coal mining has been implemented for drill rigs, haul roads, and coal refuse piles. Cyclones and water sprays are used on the larger drills to control particulates. Most states enforce water spraying of haul roads to reduce dust and improve safety. Control of gaseous pollutants from stagnant coal piles is achieved by shielding the piles from wind, applying cooling process, or removing the carbonaceous material. The open coal mining industry is experiencing a high growth rate (3.5% per year), and the growth factor for the industry (1978 emissions/1972 emissions) is 1.23.

This report was submitted in partial fulfillment of Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. The study covers the period September 1974 to July 1975, and the work was completed in September 1977.

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ABBREVIATIONS AND SYMBOLS

A	--total area of the mine
A_D	--annual land disturbance
A_j	--number of acres of surface coal land disturbed per state per year
BGD	--background
C	--constant
D	--representative distance from source
D_T	--total dosage
e_j	--emission factor for wind erosion in the jth state
E_i	--emission factor for the ith unit operation
F_p	--primary standard for particulates
K	--constant
P	--average annual coal production
P_j	--state coal production for 1972
P_R	--production rate for representative mine
Q	--emission rate
Q_c	--emission rate of coal dust from representative source
Q_{jK}	--amount of respirable dust emitted from surface coal mines of the jth coal state, for K = 1, Q_{j1} = total respirable dust rate for K = 2, Q_{j2} = respirable coal dust rate for K = 3, Q_{j3} = respirable overburden dust rate
Q_o	--emission rate of silica-containing overburden dust
Q_p	--emission rate of particulate from representative source
Q_T	--total release
S_c	--coal dust severity from open coal mining
S_o	--silica-containing overburden dust severity from open coal mining
S_p	--total respirable particulate (<7 μm) severity from open coal mining

S_R --stripping ratio

T --life expectancy

u --wind speed

X_{Kj} --composition of respirable dust in the jth coal state, weight fraction coal or overburden
for K = 1, $X_{1j} = 1.0$
for K = 2, $X_{2j} = 0.927$
for K = 3, $X_{3j} = 0.073$

X --concentration contribution of a unit operation

$X_{max,p}$ --time-averaged maximum ground level concentration of particulates

σ_y --lateral dispersion coefficient
$\sigma_y = Ax^{0.9031}$ where A is a stability constant

σ_z --vertical dispersion coefficient
$\sigma_z = Ax^B + C$ where A, B, and C are stability constants

ΣE_i --sum of the appropriate emission factors per state

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	To	Multiply by
Centimeter (cm)	Foot	3.281×10^{-2}
Joule (J)	British thermal unit	9.479×10^{-4}
Kilogram (kg)	Pound-mass (avoirdupois)	2.204
Kilogram (kg)	Ton (short, 2,000 lb mass)	1.102×10^{-3}
Kilometer^2 (km^2)	Mile^2	3.860×10^{-1}
Meter (m)	Foot	3.281
Meter^2 (m^2)	Foot^2	1.076×10^{1}
Meter^3 (m^3)	Foot^3	3.531×10^{1}
Metric ton	Pound-mass	2.205×10^{3}
Radian (rad)	Degree (°)	5.730×10^{1}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Mega	M	10^6	1 MJ = 1 x 10^6 joules
Kilo	k	10^3	1 kg = 1 x 10^3 grams
Centi	c	10^{-2}	1 cm = 1 x 10^{-2} meter
Milli	m	10^{-3}	1 mm = 1 x 10^{-3} meter
Micro	μ	10^{-6}	1 μm = 1 x 10^{-6} meter

[a]Standard for Metric Practice. ANSI/ASTM Designation E 380-76$^{\epsilon}$, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 pp.

SECTION 1

INTRODUCTION

Open coal mining encompasses strip and auger mining of coal that lies near the earth's surface, and it is used extensively in all of the coal bearing areas of the United States. This industry constitutes a source of air pollution in the form of respirable dusts. The objective of this work was to assess the environmental impact of open coal mining and to produce a reliable and timely Source Assessment Document for use by EPA in deciding on the need for emissions reduction.

This document summarizes information relating to the emissions from open coal mining. The areas studied were: 1) process and subprocess unit operations; 2) source sites; 3) mass emissions, state and nationwide; 4) effects on air quality; 5) state of the art and future considerations in pollution control technology; and 6) projected growth and anticipated technological developments of the industry.

Emission factors were developed for seven mining unit operations and for the wind erosion emission sources that are characteristic of the industry. These emission factors were used to compile the estimated effects on air quality.

SECTION 2

SUMMARY

Open coal mining is a major method of mining coal in the United States. Approximately one-half of the 546 x 10^6 metric tons[a] of the raw coal produced in 1972 was mined by open mining methods (strip and auger). Most of the open-mined coal was produced in the Eastern and Interior provinces (86%) with the balance produced in the Rocky Mountain province (14%). Nearly 50% of the coal produced in 1972 was obtained by open mining in three states: Kentucky, Ohio, and Illinois. A total of 16 states out of a possible 23 were considered in this study. The seven excluded states accounted for less than 1% each of the total annual production.

Open coal mining is characterized by a series of seven unit operations or subprocesses involving excavation of overburden, removal of the coal, and coal transport. Respirable dusts, the only hazardous emissions, are generated in five of the subprocesses. The unit operations and their contributions to the total dust loading are: coal transport unloading, 40%; blasting, 30%; coal loading, 14%; drilling, 12%; and coal augering, 1%. These unit operations contribute nearly 97% of the respirable dust emissions. The balance is attributed to wind erosion (3%).

The respirable particulate (less than 7 μm) emissions for the open coal mining industry in 1972 amounted to 3,600 metric tons. All emission rates and contributions are based on assumed emission factors. The emission factors for the unit operations indicate that 13 g of respirable dust are emitted per metric ton of coal mined. An average of 0.019 g of respirable dust is emitted via wind erosion of the mined surface per second per square kilometer of mined land. Estimates of the error in the wind erosion factor were not possible.

The respirable dust from open coal mining is composed of 93% coal and 7% overburden. The representative free silica content of the overburden is 20%, while coal averages 3% (all values being percent by weight).

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[a] 1 metric ton equals 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory material.

Emissions from the open coal mining industry constitute 0.019% of national emissions of particulates. Four of the 16 states have emissions of respirable dust exceeding 0.1% of the state total particulates. These states are Wyoming (0.17%), Kentucky (0.15%), West Virginia (0.13%), and North Dakota (0.11%).

A severity factor, S, was defined to indicate the hazard potential of the emission source:

$$S = \frac{\bar{\chi}_{max}}{F} \qquad (1)$$

where $\bar{\chi}_{max}$ is the time-averaged maximum ground level concentration of each pollutant emitted from a representative open coal mining source, and F (the primary ambient air quality standard for criteria pollutants) is a "corrected" threshold limit value for non-criteria pollutants.

The representative source was defined as a mine producing 108×10^3 metric tons of raw coal per year and having an area of 2.0 km^2. The representative mine has a life expectancy of 20 years, a stripping ratio of 13.6 m overburden/m coal, an annual land disturbance of 98.5×10^3 m^2, and is located in the Midwest (Illinois or Indiana). The total dust severity is 1.0×10^{-3}, the coal dust severity is 0.036, and the overburden dust severity is 0.014.

Control technology in open coal mining has been implemented for drill rigs, haul roads, and coal refuse piles. Cyclones and water sprays are used on the larger drills to control particulates. Most states enforce water spraying of haul roads to reduce dust and improve safety. Control of gaseous pollutants (carbon monoxide, CO; hydrocarbons; and nitrogen oxides, NO_x) from stagnant coal piles is achieved by shielding the piles from the wind, applying cooling processes, or removing the carbonaceous material. Although it is not practiced directly as a method for air pollution control, the judicious placement of explosive delays in blasting rounds can reduce dust by efficient fragmentation (small pieces of coal). No control technology is applied to other facets of the industry.

The application of chemical or water sprays during unit operations such as coal transport/unloading, loading, and augering is one viable alternative for suppression of dust during open coal mining. Windbreaks can effectively reduce visible dust emissions from coal and overburden wind erosion. The control problem is complicated by the lack of available technology for the reduction of respirable dust (less than 7 μm).

The open coal mining industry is experiencing a high growth rate (3.5% per year) primarily because of rapid development of rich

coal lands west of the Mississippi River. The open production of raw coal will increase to 312 x 10^6 metric tons in 1978. Dust emissions are expected to increase proportionately because there are no signs of control technology, if available, being applied to this industry. The growth factor for the industry (1978 emissions/1972 emissions) is 1.23.

SECTION 3

SOURCE DESCRIPTION

PROCESS DESCRIPTION

Emission Sources

Open mining of coal involves withdrawing and winning coal from surface or near subsurface coal deposits. In 1972, 263 x 10^6 metric tons, or nearly 50% of the raw coal produced in the United States, was obtained by open mining (1). Two methods are used in open coal mining: the first and most common is strip mining; the second is auger mining. Strip mining, also known as opencast mining, accounted for 95% of the surface-mined raw coal produced in 1972 (1). Auger mining is more correctly termed a secondary or auxiliary method because it is utilized to extract coal where stripping operations become uneconomical. This method accounted for the remaining 5% of the surface-mined raw coal produced in 1972 (1).

Strip mining is used in all 23 of the open coal mining states; auger mining is utilized in 8. In 1972, there were 2,309 strip mining operations and 574 auger mining operations in the United States (1). The average capacity of strip mines is 107.6 x 10^3 metric tons (1972) (1). Although less than 10% of the strip mines had capacities over 181 x 10^3 metric tons, they accounted for 70% of the 1972 strip production. The average capacity of the auger mines is 24,600 metric tons (1972) (1). The 90% of the auger operations with capacities less than 50 x 10^3 metric tons accounted for 54% of the 1972 auger coal production.

The United States Bureau of Mines has defined the terms "strip mining" (open-cast mining) and "auger mining" (2). These definitions are presented in Appendix A. Auger mining is a straightforward coal mining method, and techniques do not vary across the United States. Conversely, strip mining techniques vary

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(1) 1974 Keystone Coal Industry Manual. G. F. Nielsen, ed. McGraw-Hill, Inc., New York, New York, 1974. 859 pp.

(2) A Dictionary of Mining, Mineral, and Related Terms. P. W. Thrush, ed. U.S. Department of the Interior, Washington, D.C., 1968. 1269 pp.

widely depending on the characteristics of the coal seam deposits. Appendix A summarizes the various strip mining techniques that are practiced, and describes the current equipment utilized in both strip and auger coal mining.

The differences in strip mining techniques are defined by the types and combinations of equipment used in the mining operation. The relationship between emissions and the different mining methods must be reconciled. Although entire mining operations may vary from one region of the country to another, they share common unit operations. Unit operations are defined as distinct and self-contained processes which are used to perform the excavation and/or transport functions involved in coal mining. Unit operations in the mining sense are construed as subprocesses involving one or more items of equipment. Table 1 classifies unit operations into the basic functions, and lists the equipment normally associated with each. Figure 1 depicts the unit operations of open coal mining as they relate to the overall mining process.

TABLE 1. UNIT OPERATIONS CLASSIFICATION FOR OPEN COAL MINING IN THE UNITED STATES

Unit operation	Materials handled	Class	Function	Prime movers
Drilling	Coal, overburden	Primary operation	Excavation	Rotary drill
Overburden stripping	Overburden	Primary operation	Excavation	Dragline,[a] power shovel,[a] bucket wheel excavator, tractor-scraper, bulldozer, loading shovel, front-end loader
Coal loading	Coal	Primary operation	Excavation	Bulldozer, loading shovel,[a] front-end loader,[a] power broom
Coal transport/unloading	Coal	Primary operation	Transport	Haul truck
Blasting	Coal, overburden	Primary operation	Excavation	Explosives
Coal augering	Coal	Secondary operation	Excavation	Auger
Reclamation	Overburden	Secondary operation	Excavation and transport	Dragline, tractor-scraper,[a] bulldozer,[a] front-end loader, grader[a]

[a]Denotes major equipment type in specific unit operation.

Emissions of dust occur during each of the unit operations. The emission sources are comprised of the five primary and two secondary unit operations shown in Table 1, and wind erosion.

Source Composition

Coal and overburden, the emissions source, are exceedingly complex, widely variable entities.

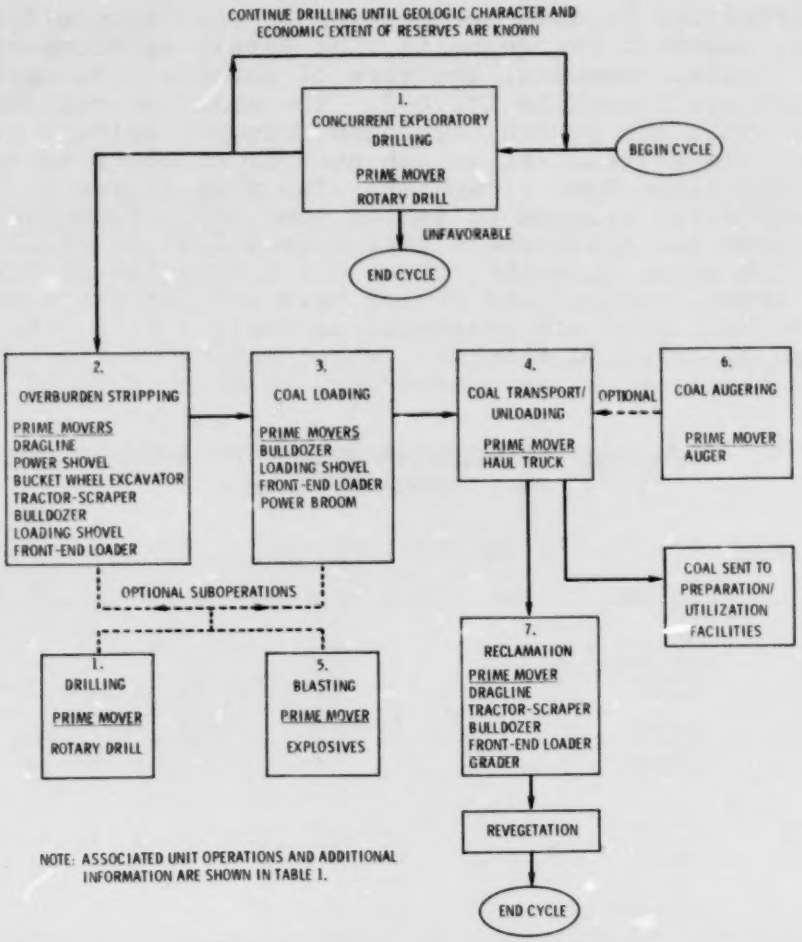

Figure 1. Open coal mining cycle of events and associated unit operations.

There are four major ranks of coal: 1) lignite, 2) bituminous, 3) subbituminous, and 4) anthracite (3). In 1972, anthracite accounted for less than 1.2% of the coal used in the United States (2, 4) and only 2% of the surface-mined coal of all ranks (1). Therefore, anthracite will not be considered in this report.

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(3) A.S.T.M. Standards on Coal and Coke. ASTM Designation D 388-38, American Society for Testing and Materials, Philadelphia, Pennsylvania, September 1948. p. 80.

(4) Minerals Yearbook, 1972; Volume I: Metals, Minerals, and Fuels. U.S. Department of the Interior, Washington, D.C., 1974. 1370 pp.

The chemical and physical properties of coal vary widely between deposits, seams in the deposits, and within sections of the seam strata. Typical chemical analyses of certain U.S. coals of various ranks are listed in Table 2. The major elements and components in coals are carbon, hydrogen, oxygen, sulfur, nitrogen, and ash. The variability in ash content of coals is important from a respirable dust viewpoint. The free silica content in coal is directly related to ash content (5). From Table 2 it can be seen that the ash content varies from 3.0% to 11.2%. In addition to the major elements, there exist a myriad of trace elements. Brown, Jacobs, and Taylor have studied trace elements in coal and their data are presented in Table 3 (6). The crustal abundance of selected elements, which refers to the concentration of trace elements in the overburden, is also included (7).

TABLE 2. ANALYSES OF SELECTED COALS OF VARIOUS RANKS (5)[a]
("As received" basis)

Rank[b]	State	Seam	Proximate analysis, %				Ultimate analysis, %					Heating value, MJ/kg
			Moisture	Volatile matter	Fixed carbon	Ash	Carbon	Hydrogen	Oxygen	Sulfur	Nitrogen	
Bituminous:												
Low-volatile	West Virginia	Pocahontas No. 3	3.5	18.2	74.4	3.9	84.0	4.8	5.6	0.6	1.1	33.8
Medium-volatile	West Virginia	Sewell	3.1	25.0	66.8	5.1				1.3		33.2
High-volatile A	Pennsylvania	Pittsburgh	2.6	30.0	58.3	9.1	76.6	5.2	6.2	1.3	1.6	31.6
High-volatile A	Kentucky	Elkhorn	3.1	35.0	58.9	3.0	79.2	4.7	10.0	0.6	1.5	33.2
High-volatile B	Ohio	Middle Kittanning	8.2	36.1	48.7	7.0	68.4	5.6	16.4	1.2	1.4	28.3
High-volatile B	Kentucky	No. 6	7.2	39.8	48.8	4.2	71.5	5.8	14.3	2.6	1.6	30.1
High-volatile C	Illinois	No. 2	12.1	40.2	39.1	8.6	62.8	5.9	17.4	4.3	1.0	26.7
High-volatile C	Indiana	No. 6	12.4	36.6	42.3	8.7	63.4	5.7	18.6	2.3	1.3	26.5
Subbituminous:												
Subbituminous A or high-volatile bituminous C	Wyoming	Uncorrelated	16.5	34.2	38.1	11.2				2.1		22.6
Subbituminous B	Wyoming	Monarch	23.2	33.3	39.7	3.8	54.6	6.4	33.8	0.4	1.0	21.9
Subbituminous C	Wyoming	Uncorrelated	24.6	27.7	39.9	7.8				1.1		20.0
Lignite:												
Lignite	North Dakota	Beulah	34.8	28.2	30.8	6.2	42.4	6.7	43.3	0.7	1.7	16.8

[a] Blanks indicate data not reported in reference.

[b] According to A.S.T.M. method of classification.

(5) Chemical Engineers' Handbook, Fourth Edition. J. H. Perry, ed. McGraw-Hill Book Company, New York, New York, 1963. 1650 pp.

(6) Brown, R., M. L. Jacobs, and H. E. Taylor. A Survey of the Most Recent Applications of Spark Source Mass Spectrometry. American Laboratory, 4(11):29-40, 1972.

(7) Abernethy, R. F., M. J. Peterson, and F. H. Gibson. Spectrochemical Analyses of Coal Ash for Trace Elements. Bureau of Mines RI-7281, U.S. Department of the Interior, Washington, D.C., July 1969. 30 pp.

TABLE 3. CONCENTRATIONS OF TRACE ELEMENTS IN COAL[a]

Element	ppm in Coal (6)	Crustal abundance (7), ppm
Aluminum	Major	Major
Arsenic	0.30	1.8
Barium	69	425
Bismuth	0.2	0.2
Bromine	0.30	
Boron	42	10.0
Cadmium	0.19	
Calcium	4,000	
Cerium	13	60
Chlorine	130	
Chromium	4.5	100
Cobalt	2.3	25
Copper	25	55
Fluorine	5.7	
Gallium	8.7	15
Germanium	0.33	1.5
Iodine	0.20	
Iron	1,600	
Lanthanum	5.8	30
Lead	3.9	13
Magnesium	4,500	
Manganese	30	950
Molybdenum	3.0	1.5
Neodymium	8.3	28
Nickel	2.7	75
Niobium	20	20
Phosphorus	380	
Potassium	410	
Praseodymium	4.7	
Rubidium	3.0	90
Samarium	1.7	
Scandium	1.3	22
Selenium	0.32	
Silicon	Major	Major
Silver	0.22	
Sodium	5,000	
Strontium	100	375
Sulfur	6,100	
Tellurium	0.25	
Titanium	620	
Uranium	1.9	
Vanadium	12	135
Yttrium	7.7	33
Zinc	10	70
Zirconium	76	165

[a]Blanks indicate data not reported in reference.

The overburden is composed primarily of soil and minerals (rock). Sand, silt, and clay are the basic constituents of soil. Soil categories and the defined particle size ranges of soils are shown in Figure 2 (8). This discussion will be limited solely to hazardous components of rock and soil, namely siliceous materials.

Both soil and rock contain amounts of free silica, which occurs in soils mainly in the form of quartz, SiO_2 (9, 10). Quartz silica is found in alluvial soils, various types of sedimentary rocks, and residual crystalline rocks. Free silica occurs as opal (including opal pseudomorphic afterplant cells -- phytoliths), chalcedonite, agate, flint, chert, and cristobalite, which is predominant in the lavas of the San Juan coal district of Colorado (2). It is also found in the form of amorphous sheets and as aggregates with amorphous iron and aluminum oxide gel.

Igneous rock, shale, or sandstone is frequently encountered in surface coal mining. A typical representation of coal-bearing strata of the Western United States is shown in Figure 3 (11). Igneous rock contains an average of 12% free silica as quartz (12), shale averages 22.3%, and sandstone averages 66.8%.

There is no distinct separation of coal and overburden in surface coal mining. Figure 3 shows that coal seams are stratified. Thus, mining produces a composite of varying amounts of coal and overburden.

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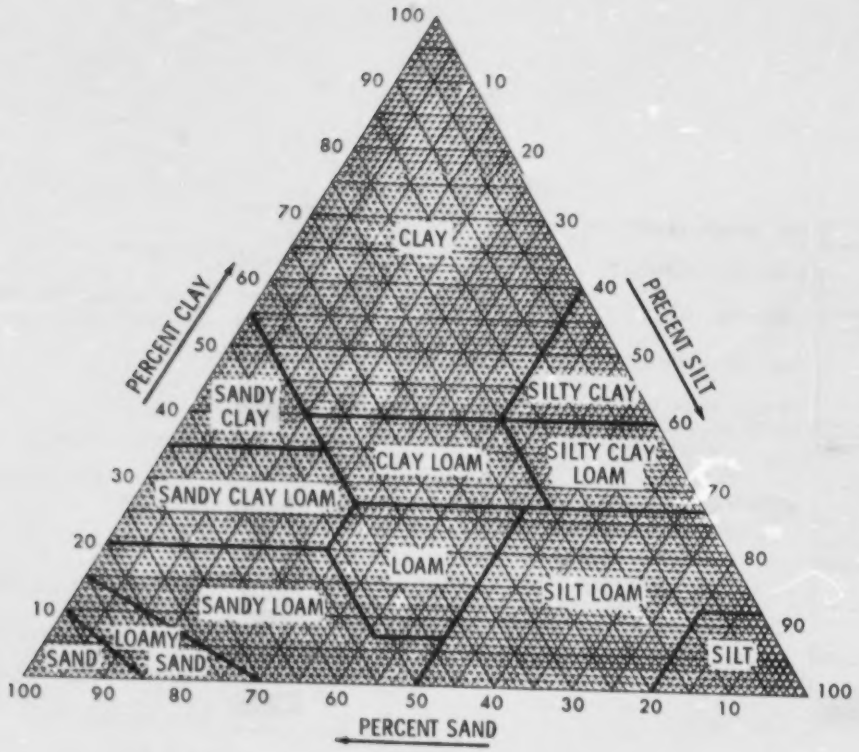
(8) Brunner, D. R., and D. J. Keller. Sanitary Landfill Design and Operation. Report SW-65ts, U.S. Environmental Protection Agency, Washington, D.C., 1972. p. 16.

(9) Jahr, D. J. Proposed Threshold Limit Values for Dusts Containing Free Silica. Staub Reinhaltung der Luft (in English), 33:86-90, February 1973.

(10) Chemistry of the Soil, Second Edition. F. E. Bear, ed. Reinhold Publishing Corporation, New York, New York, 1965. 502 pp.

(11) Shoemaker, J. W., E. C. Beaumont, and F. E. Kottlewski. Strippable Low-Sulfur Coal Resources of the San Juan Basin in New Mexico and Colorado. Memoir No. 25, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, 1971.

(12) Foth, H. D., and L. M. Turk. Fundamentals of Soil Science, Fifth Edition. John Wiley & Sons, Inc., New York, New York, 1972. 442 pp.



SAND – 2.0 TO 0.05 mm DIAMETER
SILT – 0.05 TO 0.002 mm DIAMETER
CLAY – SMALLER THAN 0.002 mm DIAMETER

COMPARISON OF PARTICLE SIZE SCALES

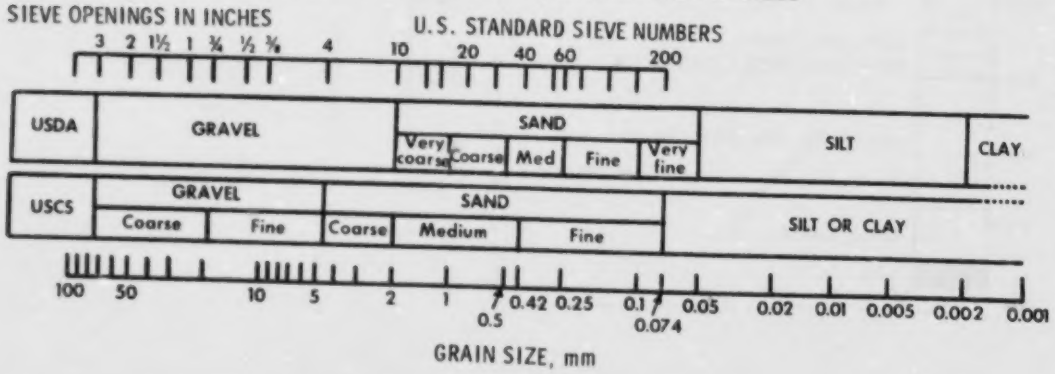


Figure 2. Textural classification chart (U.S. Department of Agriculure) and comparison of particle size scales (8).

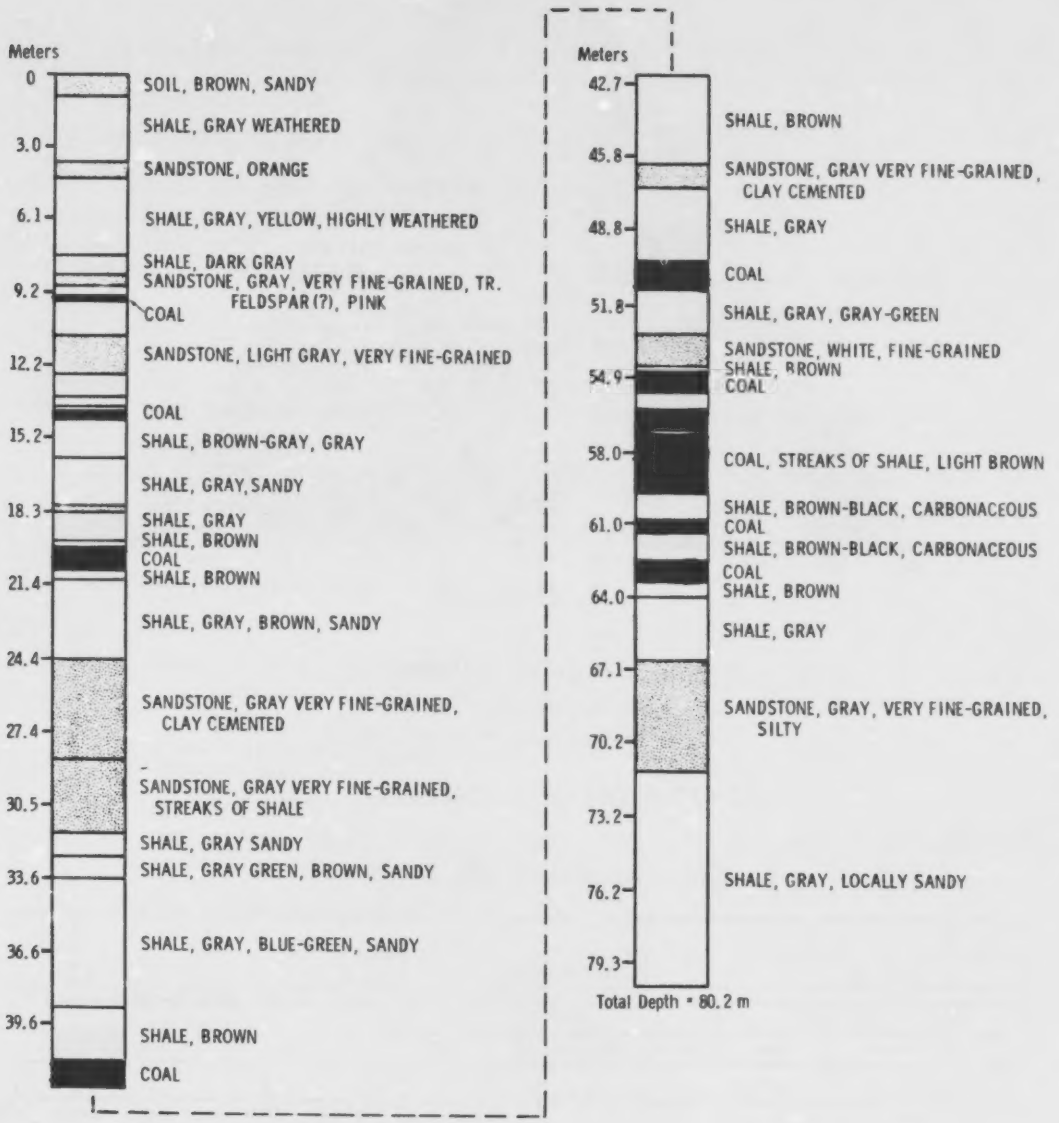


Figure 3. Typical Western U.S. coal-bearing strata (11).

Coalbed gas is emitted to the atmosphere during the mining operation. The primary constituents are methane (63% to 99%), carbon dioxide, and trace amounts of C_{2-5} hydrocarbons (13, 14). As coal weathers in mined-out portions of the workings, it slowly oxidizes to CO and carbon dioxide (CO_2).

Explosive detonations represent another source of atmospheric emissions. The predominant blasting agent in surface mining is ANFO (ammonium nitrate and fuel oil) (15-17). ANFO accounted for over 90% of the 431 x 10^3 metric tons of explosives used by the coal industry in 1972 (17). A typical blasting mixture consists of 94.5% by weight ammonium nitrate (NH_4NO_3) and 5.5% by weight fuel oil. Toxic byproducts of the explosive reaction are CO, nitrous oxide (NO), and nitrogen dioxide (NO_2) fumes (18).

FACTORS INFLUENCING EMISSIONS

Open coal mining is a complex emissions source with respirable dust emissions emanating from seven possible unit operations within the mine (see Table 1) plus windblown dust as a result of mining activity. This section identifies the parameters which influence the generation of respirable dust from wind forces and from each of the seven unit operations. Respirable dust is the only pollutant type considered in the study of open coal mining. Minor emission sources and the reasons for their exclusion are discussed in Section 4.

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(13) Kim. A. G. The Composition of Coalbed Gas. Bureau of Mines RI-7762 (PB 221 574), U.S. Department of the Interior, Washington, D.C., May 1973. 13 pp.

(14) Krickovic, S., and C. Findlay. Methane Emission Rate Studies in a Central Pennsylvania Mine. Bureau of Mines RI-7591 (PB 206 359), U.S. Department of the Interior, Washington, D.C., 1971. 9 pp.

(15) Surface Mining, E. P. Pfleider, ed. American Institute of Mining, Metallurgical and Petroleum Ingineers, Inc., New York, New York, 1972. 1048 pp.

(16) Woodruff, S. D. Methods of Working Coal and Metal Mines, Volume 3. Pergamon Press, New York, New York, 1966. 571 pp.

(17) 1972 Census of Mineral Industries (SIC 1211), Bituminous Coal and Lignite. MIC72(P)-12A-1, U.S. Department of Commerce, Washington, D.C., April 1974. 7 pp.

(18) Chaiken, R. F., E. B. Cook, and T. C. Ruhe. Toxic Fumes from Explosives; Ammonium Nitrate-Fuel Oil Mixtures. Bureau of Mines RI-7867 (PB 233 496), U.S. Department of the Interior, Washington, D.C., May 1974. 29 pp.

Emission Parameters for Wind Erosion of Mined Land

As wind blows across the surface of a coal mine, respirable particles consisting of coal and soil become entrained. The major parameters governing respirable dust particle movement from open coal mining surfaces are the size distribution of particles in the soil and the local climatic factors (wind, moisture, temperature). Minor parameters include the soil surface roughness, distance across the field, distance sheltered by barriers, and form of vegetation on the surface. Woodruff and Siddoway (19) have confirmed Chepil's original assumptions and experimental work on the mechanisms describing the air entrainment of dust particles of all sizes from soils. Jenne (20) summarized Chepil's mechanisms of movement of individual particles on a soil surface as: 1) sliding or rolling of particles along the surface (surface creep); 2) movement by leaps and bounds (saltation); and 3) movement by airborne transport (suspension). The larger particles (greater than 100 μm) are affected mostly by saltation with some surface creep. Particles closer in size to the respirable range (less than 50 μm) are readily dislodged, and large volumes are carried into suspension by impacts from larger grains moving in saltation (20). Impaction of larger particles releases smaller adsorbed particles because the cohesive forces are weakened.

Climatic factors, such as wind speed, temperature, and precipitation, affect the respirable dust emissions from soil. Thornthwaite (21) combined the effects of temperature and precipitation into a single parameter called the precipitation-evaporation index (P-E index). Under saturated soil moisture conditions there are no respirable emissions at any wind speed. Neither the functionality relating the climatic factors to the respirable dust emission rate nor the exact mathematical functionalities for each of the seven unit operations which follow are known.

Emission Parameters for Rotary Drilling

Rotary bit drills are used to bore holes in overburden and/or coal (see Figure 11, Section 6). The holes are filled with an

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(19) Woodruff, N. P., and F. H. Siddoway. A Wind Erosion Equation. Soil Science Society of America, Proceedings, 29(5): 602-608, 1965.

(20) Jenne, D. E. An Analysis of High Volume Particulate Sampling Data in Benton, Franklin, and Walla Walla Counties of Washington - 1970, 1973. Benton-Franklin-Walla Walla Counties Air Pollution Control Authority, Hanford, Washington, June 1974. 37 pp.

(21) Thornthwaite, C. W. Climates of North America According to a New Classification. Geographical Review, 21:633-655, March 1931.

explosive and shot. This unit operation involves a single equipment type. The drill bit, which employs compressed air through its hollow core to remove cuttings and to cool the bearings (15), produces respirable dust. The rate of uncontrolled emissions is influenced by the complex interaction of the rate of bore hole descent, bulk moisture content of material worked, diameter of bore hole, downthrust applied to the drill bit, amount of air supplied to the bit, and size distribution of material in the cuttings. The continuous comminution of particles by the shearing action of the drill bit generates respirable emissions (less than 7 μm).

Emission Parameters for Overburden Stripping

The unit operation of overburden stripping is simple in nature, involving the removal of topsoil and consolidated or unconsolidated material above the coalbed. However, seven different types of equipment are utilized throughout the industry (see Table 1), the dragline and the power shovel being the predominant types. Although the equipment varies widely in physical appearance, it performs the same function. The respirable emissions from each equipment type are influenced by common parameters. The variables affecting the quantity of respirable dust emitted are bulk moisture content of soil, size distribution of particles in the undisturbed material, struck volumetric capacity,[a] and the efficiency of stripping, which accounts for variability in emission rates between equipment types. The efficiency is inversely proportional to cycle time per metric ton of material excavated. The cycle time per metric ton for a given piece of equipment is the time required to load, swing, and dump a quantity of material. For example, the efficiency of stripping is lower for a dragline than for a stationary front-end loader of comparable size because the dragline has a longer cycle time (15).

Emission Parameters for Coal Loading

Coal loading entails the removal and dumping of coal from the exposed coal seam. It is a complex unit operation requiring four types of equipment; the loading shovel and front-end loader are predominant (see Table 1). The generation of respirable dust from this operation is a function of the coal's brittleness (commonly called the Hardgrove Grindability) and moisture content, size distribution of loosened coal, efficiency of loading (similar to efficiency of stripping overburden), and the struck volume capacity of the loading machine. The Hardgrove Grindability Index of coal is a number between 0 and 100 showing the relative hardness or the friability of coal in relation to a standard coal with a grindability index of 100 (2).

[a]The capacity of a mine car, tram, hopper, or wagon to the flat surface at the edges (2).

Emission Parameters for Coal Transport/Unloading

This single equipment type unit operation consists of trucking the coal to the dump site (usually located near the mine tipple). Emissions of respirable dust are generated by the truck tires on the haul road en route to the tipple and back to the loading point, and by the dumping of coal at the mine tipple. Wind erosion of the coal in the truck en route to the mine tipple is insignificant (22). The respirable emissions due to vehicular movement on the unpaved dry haul roads are influenced by vehicle speed, vehicle dimensions, number and width of the wheels, particle size distribution and moisture content of the unpaved road surface, and distance of unpaved road round trip from loading point to tipple.

Respirable dust is also generated during unloading of the coal at the tipple. The emissions from coal unloading are a function of the same factors as those that affect loading emissions with the exception of the unloading efficiency parameter. The unloading efficiency term is absent because only trucks are used in this unit operation. The influencing parameters for coal unloading are the struck volume of the coal truck, moisture content of the coal, Hardgrove Grindability, and the size distribution of coal within the truck.

Emission Parameters for Blasting Coal and Overburden

Blasting is a separate and distinct unit operation which generates respirable dusts. It is employed to loosen overburden and/or coal prior to removal. The mass emission rate for blasting depends on the quantity of charge used, the number of holes fired, the diameter of the holes, the average millisecond (ms) delay time between hole firings, the bulk moisture content of the soil or coal and the particle size distribution of the bulk soil or coal (post blast). The millisecond delay time between hole firings is an important parameter in predicting rock fragmentation characteristics. Langefors and Kilhström (23) report that blasting delays less than 10 ms produce an abundance of small rock fragments (less than 40 cm) while delays greater than 10 ms produce large fragments. Delay time is included as a parameter related to respirable dust mass emissions, because it is assumed that the generation of respirable dust will be proportional to the degree of fragmentation.

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(22) Blackwood, T. R., and P. K. Chalekode. Source Assessment: Transport of Sand and Gravel. Contract 68-02-1320, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Preliminary document submitted to the EPA by Monsanto Research Corporation, November 1974.) 86 pp.

(23) Langefors, U., and B. Kihlström. The Modern Technique of Rock Blasting. John Wiley & Sons, Inc., New York, New York, 1963. 405 pp.

Emission Parameters for Auxiliary Operations - Coal Augering

The parameters governing horizontal augering into the remaining highwall are similar to those of rotary drilling. This unit operation involves a single equipment type, namely the single or multiple coal auger. The auger, unlike the drill, supplies no air to the auger tip to remove coal cuttings. Rather, the coal is fed out of the hole with action similar to that of a wood-boring drill. The factors influencing respirable dust emissions are the rate of penetration into the coal seam, bulk coal moisture, diameter of auger, number of augers, sidethrust applied to auger, and the size distribution of coal resulting from augering.

Emission Parameters for Auxiliary Operations - Reclamation

Reclamation of strip-mined lands involves recontouring the depleted open pit to specific state requirements. This operation typically involves a variety of equipment types to smooth over the displaced overburden spoil banks. The dragline-bulldozer combination is chosen as representative of the industry since it is used at over 50% of the mines. The dragline employed has a lower capacity than those utilized in stripping. The smaller dragline excavates the required fill material so that the bulldozer can level the mined workings. This method permits strategic placement of valuable topsoil. The emission rate for the reclamation unit operation is thus a function of two equipment types: bulldozer and dragline. As such, the parameters influencing dust generation from overburden stripping by dragline are directly applicable. The emissions from bulldozers are functions of blade width, horsepower, bulk moisture content of soil, and size distribution of particles in the soil.

GEOGRAPHICAL DISTRIBUTION

Surface coal mining occurs in 23 of the 48 conterminous states; 16 of these states produced over 95% of the strip-mined coal and over 99% of the auger-mined coal in 1972. The 16 states are listed in Table 4, which includes the 7 states that were not considered because of their low productivity (each state accounted for less than or equal to 1% of the total production). The strip mining method was predominant in the 16 states studied; 94% of the surface coal was strip mined. Auger mining accounted for 6% of the surface production. Kentucky was the leading producer of surface coal in 1972. The combined tonnage of the second and third largest producers, Ohio and Illinois, respectively, approximately equaled that of Kentucky.

Figure 4 depicts P-E regions (U.S. Weather Bureau county groupings within states) that are major producers of surface coal. It also indicates 1972 surface coal production by P-E region and associated population density per region. The P-E regions were chosen as geographical boundaries because climatic data are organized on a P-E regional basis.

TABLE 4. STATE PRODUCTION OF SURFACE-MINED COAL BY PRODUCTION RANKING FOR 1972 (1)
(10^3 metric tons)

Rank	State	Strip tonnage	Strip %	Auger tonnage	Auger %	Total	Total %
1	Kentucky	50,599	20.3	8,089	57.3	58,688	22.3
2	Ohio	30,914	12.4	563	4.0	31,477	11.9
3	Illinois	30,665	12.3	0	0	30,665	11.6
4	Pennsylvania	23,826	9.5	492	3.5	24,318	9.2
5	Indiana	22,229	8.9	0	0	22,229	8.4
6	West Virginia	17,328	6.9	2,702	19.2	20,030	7.6
7	Alabama	11,954	4.8	44	0.3	11,998	4.5
8	Wyoming	9,514	3.8	0	0	9,514	3.6
9	Virginia	7,198	2.9	1,905	13.5	9,103	3.4
10	Montana	7,442	3.0	0	0	7,442	2.8
11	New Mexico	6,563	2.6	0	0	6,563	2.5
12	North Dakota	6,016	2.4	0	0	6,016	2.3
13	Tennessee	4,638	1.8	255	1.8	4,893	1.9
14	Missouri	4,129	1.6	0	0	4,129	1.6
15	Texas	3,670	1.5	0	0	3,670	1.4
16	Arizona	2,680	1.1	0	0	2,680	1.0
Total of 16 highest ranked states		239,365	95.8	14,050	99.6	253,415	96.1
The following states are not considered in this report							
17	Washington	2,364	0.9	0	0	2,364	0.9
18	Oklahoma	2,301	0.9	0	0	2,301	0.9
19	Colorado	2,224	0.9	0	0	2,224	0.8
20	Maryland	1,302	0.6	59	0.4	1,361	0.5
21	Kansas	1,113	0.4	0	0	1,113	0.4
22	Iowa	453	0.3	0	0	453	0.2
23	Arkansas	381	0.2	0	0	381	0.1
Total of states ranked 17 to 23		10,138	4.2	59	0.4	10,197	3.9

In general, coal is surface mined in areas remote from population concentration. Comparison of the location of surface mines to population density by P-E region indicates that surface mining occurs in regions with population densities as low as 0.48 persons/km^2 (western states) and in regions as high as 145 persons/km^2 (eastern states). The average population density for the surface coal industry is 27 persons/km^2.

Figure 4. Coal production by P-E region (10^3 metric tons strip and auger) and population density.

(continued)

NOTE: UPPER FIGURES SHOW COAL PRODUCTION; LOWER FIGURES SHOW POPULATION DENSITY.

Figure 4 (continued)

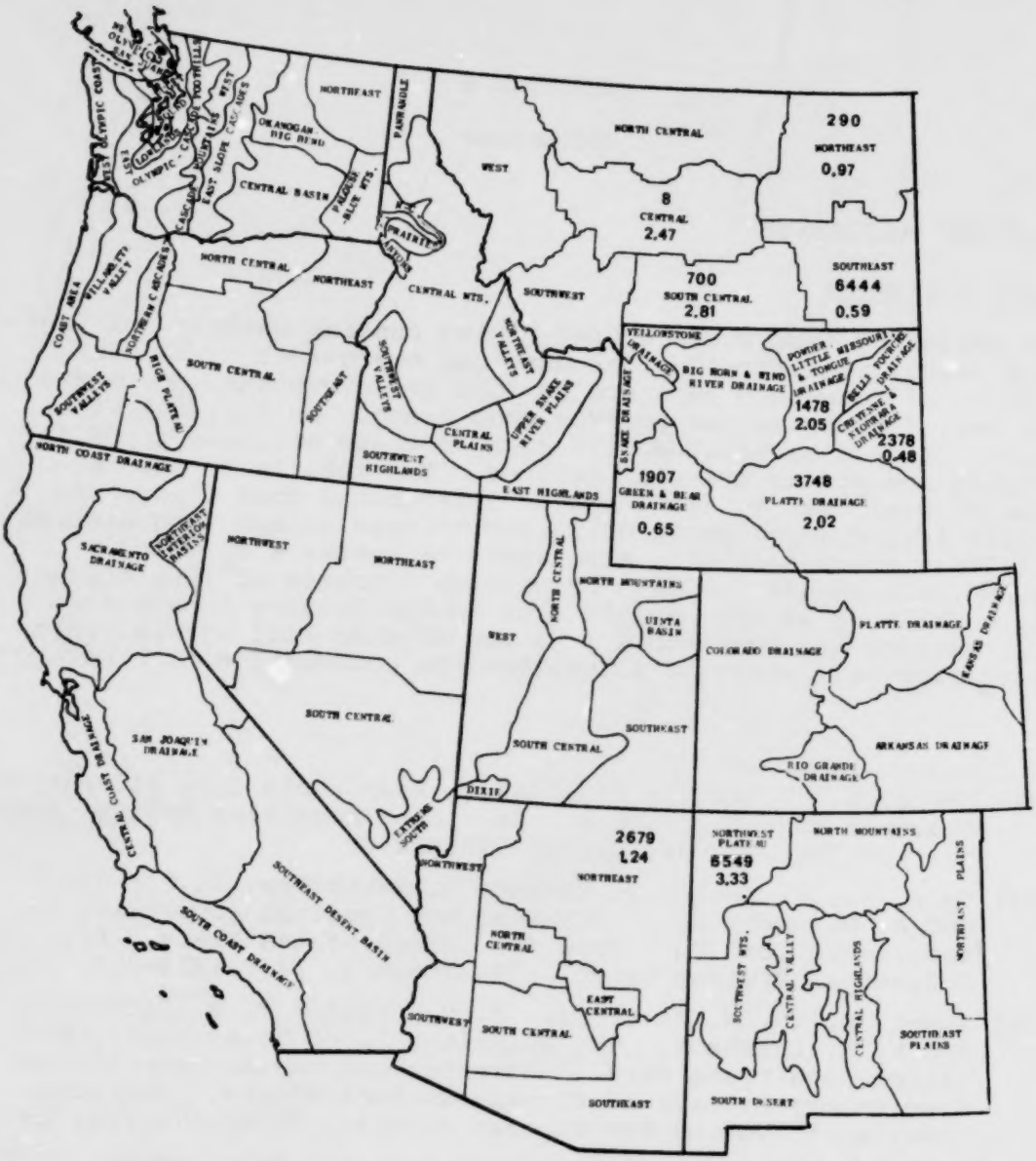

Figure 4 (continued)

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

Major Emissions

The emissions from surface coal mining consist entirely of fugitive dusts, specifically coal dust and overburden dust. The effects of long-term exposure to coal and overburden dusts are not well documented for surface coal mines. In contrast, the health hazards associated with each of these emission types in related industries are well defined. The inhalation and retention of coal dust in the lungs of underground coal miners can result in the development of pneumoconiosis (black lung disease) (24-28). Pneumoconiosis, also known as potter's or miner's asthma, can result in death by massive fibrosis of lung tissue (2). While it is not implied that health hazards to surface coal workers are comparable to those of deep coal miners, this discussion will serve to illustrate the potential health hazard

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(24) Cheng, L. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Hygiene Association Journal, 34(12):540-546, 1973.

(25) Corn, M., F. Stein, Y. Hammad, S. Manekshaw, R. Freedman, and A. M. Hartstein. Physical and Chemical Properties of Respirable Coal Dust from Two United States Mines. American Industrial Hygiene Association Journal, 34(7):279-285, 1973.

(26) Sweet, D. V., W. E. Crouse, J. V. Crable, J. R. Carlberg, and W. S. Lainhart. The Relationship of Total Dust, Free Silica, and Trace Metal Concentrations to the Occupational Respiratory Disease of Bituminous Coal Miners. American Industrial Hygiene Association Journal, 35(8):479-488, 1974.

(27) Schlick, D. P. Respirable Dust Sampling Requirements Under the Federal Coal Mine Health and Safety Act of 1969. Bureau of Mines IC-8484, U.S. Department of the Interior, Washington, D.C., July 1970. 35 pp.

(28) Cheng, L., and P. P. Zukovich. Respirable Dust Adhering to Run-of-Face Bituminous Coals. Bureau of Mines RI-7765, U.S. Department of the Interior, Washington, D.C., 1973. 10 pp.

to surface coal workers and the rationale behind the selection of coal dust as one of the two characteristic pollutants.

The threshold limit value (TLV®) for coal dust ranges from 0.5 mg/m^3 to 2.0 mg/m^3 as defined by the ACGIH (29). The variability of the TLV depends on the percent of quartz in the dust. A TLV of 2.0 is used when the quartz (SiO_2) content is less than 5.0% by weight. If the quartz content of the respirable dust is greater than 5.0%, a TLV of 10/(% quartz + 2) is recommended. The latter TLV is also applicable for quartz-predominating dusts.

The primary hazard of the dust generated from handling overburden is its free silica content (quartz, cristobalite, tridymite, etc.). The composition of the particulates emitted during overburden handling is displayed in Table 5. These data represent overburden dusts from an Illinois strip mine. The predominantly hazardous component, as in coal dust, is free silica as indicated by the quartz levels. No fibrous constituents (asbestos, serpentine quartz, etc.) were found in any of the dusts.

TABLE 5. OVERBURDEN DUST COMPOSITION FROM AN ILLINOIS STRIP MINE
(wt %)

Element/ compound	Sample 1	Sample 2	Sample 3
Silicon	>10	>10	>10
Iron	>10	>10	>10
Aluminum	5 to 10	5 to 10	5 to 10
Calcium	>10	>10	>10
Sodium	4	0.5	2
Magnesium	8	4	6
Titanium	2	2	0.8
Manganese	0.5	0.5	0.5
Chlorine	0.2	0.09	0.8
Sulfur	10 to 15	10 to 15	4
Potassium	10 to 15	10	10
SiO_2 (quartz)	16	20	23

(29) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1973. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1973. 94 pp.

The prolonged inhalation of dusts containing free silica may result in the development of a disabling pulmonary fibrosis most commonly known as silicosis. The action of free silica on the lungs results in diffuse, nodular fibrosis which is progressive and may continue to increase for several years after exposure is terminated (2). The clinical onset of uncomplicated silicosis is shortness of breath on exertion, sometimes accompanied by dry cough. Where the disease advances, the shortness of breath becomes more acute and the cough more troublesome. Further progress of the disease results in marked fatigue, loss of appetite, pleuritic pain, and total incapacity to work. Extreme cases may eventually result in death from destruction of the lung tissues.

The ACGIH has suggested a TLV of 10/(% quartz + 2) mg/m^3 for respirable dusts containing quartz in the form of free silica (29). Cristobalite- and tridymite-containing dusts have values one-half that calculated from the quartz formula.

Assuming that the biological effects of the composite dust (coal + overburden) are additive, a composite TLV may be defined (29). For coal containing less than 5% by weight quartz, the TLV in mg/m^3 of the composite respirable dust is given by:

$$\left.TLV\right|_{\text{Coal } <5\% \text{ } SiO_2} = \frac{10.0}{5.0X_c + (1-X_c)(Z_1 + 2.0)} \qquad (2)$$

where X_c = wt fraction of respirable coal dust in composite dust
Z_1 = wt % of pure respirable quartz dust in noncoal dust

If the coal contains more than 5% by weight quartz, the TLV of coal dust becomes that of quartz-bearing dust. The composite TLV is then:

$$\left.TLV\right|_{\text{Coal } >5\% \text{ } SiO_2} = \frac{10.0}{X_c(Z_2 + 2.0) + (1-X_c)(Z_1 + 2.0)} \qquad (3)$$

where Z_2 = wt % of pure respirable quartz dust in coal dust

When toxic impurities (i.e., coal or SiO_2) do not represent more than 1.0% by weight of the composite dust, the TLV becomes that of an "inert" dust (10.0 mg/m^3) and would be treated as total particulates of criteria pollutants (29).

Minor Emission Sources

The specific emission sources excluded from this environmental source assessment, because they were not considered to be

characteristic of open coal mining, are discussed in this section. Respirable particulates and gaseous emissions (NO_x, CO, and hydrocarbons) from diesel-powered equipment were not selected as characteristic because these emissions constitute a mobile source where control technology is generally available or in the process of development.

Gaseous emissions from other operations were excluded. Examples are toxic gases (NO, NO_2, CO) that are formed by the detonation of ammonium nitrate-fuel oil mixtures (18). Trace quantities of these gases were detected in confined quarters such as underground mines (18). Open field sampling and chemical analyses were performed to determine the presence of hazardous constituents (including NO, NO_2, and CO) in samples of gases from the blasting unit operation. Results indicate that these compounds are not present in measurable quantities. As a result, toxic fumes from blasting are not considered an environmental hazard.

The hydrocarbons and other gases released from coal as it is mined represent another gaseous emission source. These gases are predominantly methane (98%) with traces (1 ppm to 20 ppm) of ethylene, propane, propylene, butanes, pentanes, hydrogen, helium, oxygen, and nitrogen (13, 14, 30). Thus, it is reasonable to assume that all coalbed gas is pure methane. A survey conducted in 1973 indicated that a total of 6.08×10^6 m^3 of methane is released from U.S. underground coal mines daily (30). Using the total 1973 underground coal tonnage production of 273.5×10^6 metric tons, the emission ratio of methane per metric ton of coal is about 3.9 kg/metric ton. Assuming that the production of methane is the same for surface coal, a nationwide emission rate of 31.3 g/s is estimated for the surface coal industry. This emission rate constitutes 23% of the total mass emission rate from the industry (as noted later in this section). However, methane gas is hazardous only from the standpoint of asphyxiation (TLV = 1,000 ppm) (29). Coalbed gas was therefore neglected as an emission source because of the low hazard associated with it. The severity associated with this gas was calculated for the representative source (mean size coal mine) and was found to be 0.0033 (national emission burden of 0.0038% of total hydrocarbon emissions).

The gases (CO and CO_2) formed by the slow oxidation of coal as it weathers in mined-out portions of the workings and in storage piles are considered minor. Preliminary work has shown that these gases can be neglected as an emissions source for coal

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(30) Irani, M. C., et al. Methane Emission from U.S. Coal Mines in 1973, A Survey. Supplement to Bureau of Mines IC-8558, U.S. Department of the Interior, Washington, D.C., December 1974. 52 pp.

storage piles near power plants (31). Exclusion of this emission source is further justified because coal is seldom stored at surface mines and does not remain uncovered for the length of time necessary to generate measurable quantities of gas (31).

Particle Size Analysis

The particle size distribution of overburden dust was determined from presurvey samples gathered during sampling at one mine. Filters from high-volume samplers were observed using optical microscopy techniques (32), and the number of particles in random fields were counted. Results are shown in Figure 5. The log-normal distribution indicates the presence of processes which continuously comminute particles; i.e., unit operations. Particle sizing of coal dust was not performed.

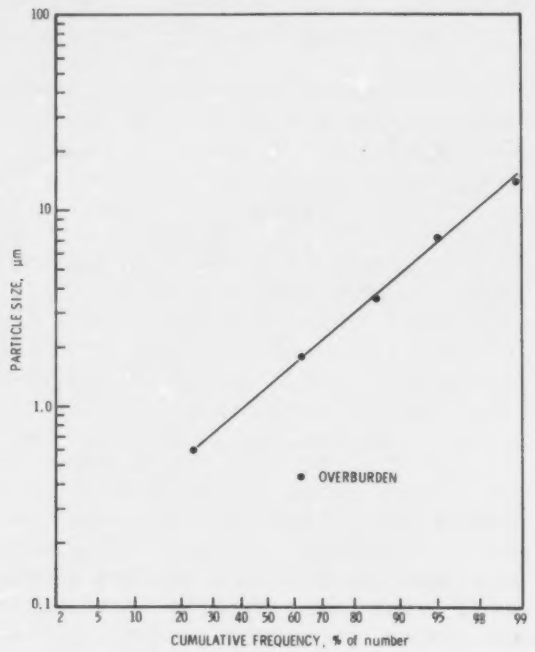

Figure 5. Particle size distribution of overburden dust (log-normal).

(31) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. July 1977, 84 pp.

(32) Blackwood, T. R., T. F. Boyle, T. L. Peltier, J. V. Pustinger, and D. L. Zanders. Fugitive Dust from Mining Operations - Appendix. Contract 68-02-1320, Task 10, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Final report submitted to the EPA by Monsanto Research Corporation, September, 1975.) 65 pp.

Emission Factors

Exact calculation of the state and national emission rates of respirable dust presupposes knowledge of the emission rate for every mine in the country. The large number of strip and auger mines precludes the gathering of such data (23, 26). A method was developed in this study to obtain estimated statistical emission factors from field sampling for each of the seven characteristic unit operations and wind erosion (see Appendix B). The emission factor is useful in predicting emission rates over large areas. Multiplying the emission factors by appropriate weighting factors yields the emission rate. A summary of the rounded emission factors developed is presented in Table 6. The wind erosion emission factors were obtained from the methods presented by Woodruff and Siddoway (18). Although the literature values computed per state account for both respirable and nonrespirable particle mass emissions, the values obtained can be considered "worst case" estimates for respirable dust. The unit operation emission factors were obtained solely from field sampling as no data were available in the literature. Besides the methodology, Appendix B summarizes the assumptions used to arrive at these estimated emission factors. Error estimates given are at the 95% confidence level.

TABLE 6. EMISSION FACTORS FOR OPEN COAL MINING

For unit operations					For wind erosion	
Unit operation	No. of samples	Emission factor, g/metric ton	Standard deviation	95% Confidence interval[a]	State	Emission factor, $[(g/s \cdot km^2)10^3]$[b]
Drilling	4	1.6	0.63	1.0	Alabama	7.47
Overburden stripping	6[b]	-[c]	-[c]	-[c]	Arizona	56.2
Coal loading	4	2.0	1.4	2.3	Illinois	11.7
Coal transport and unloading	3	5.4	2.8	7.0	Indiana	6.05
Blasting	2	4.28	0.13	±1.6	Kentucky	7.47
Coal augering	-[c]	0.08[d]	-[c]	-[c]	Missouri	11.7
Reclamation	4[c]	-[c]	-[c]	-[c]	North Dakota	52.0
Total	-[c]	13[e]	-[c]	-[c]	New Mexico	56.2
					Ohio	7.47
					Pennsylvania	7.47
					Tennessee	11.7
					Texas	89.0
					Virginia	7.47
					West Virginia	7.47
					Wyoming	56.2

Note.—Data may not add to totals due to independent rounding.

[a] Estimate of the confidence interval from observed population standard deviation using "student t" distribution.

[b] Not included in total.

[c] Not applicable.

[d] Estimated from drilling emission factor.

[e] Total emission factor on a national basis.

Mass Emission Rates and Contribution to Total Air Emission

The statewide emission rate of respirable dusts from surface coal mining was estimated from the unit operation emission factors multiplied by the state annual coal production plus the state acreage disturbed, multiplied by the wind erosion emission

factor. A composition term was included to arrive at the emission rates for coal dust and overburden dusts. Samples of coal mine dusts collected during field sampling indicate that the respirable dust contains on the average 93% coal and 7% overburden dusts. The emission rates can be expressed mathematically as:

$$Q_{jK} = A_j e_j X_{Kj} + 3.17 \times 10^{-8} P_j X_{Kj} \sum_{i=1}^{6} E_i \qquad (4)$$

where Q_{jK} = amount of respirable dust emitted from surface coal mines of the jth coal state, g/s
for K = 1, Q_{j1} = total respirable dust rate
for K = 2, Q_{j2} = respirable coal dust rate
for K = 3, Q_{j3} = respirable overburden dust rate

X_{Kj} = composition of respirable dust in the jth coal state, weight fraction coal or overburden
for K = 1, $X_{1j} = 1.0$
for K = 2, $X_{2j} = 0.93$
for K = 3, $X_{3j} = 0.07$

A_j = number of acres of surface coal land disturbed per state per year, km^2

P_j = state annual coal production, metric tons/year

E_i = emission factor for the ith unit operation, g/metric ton coal

e_j = emission factor for wind erosion in the jth state, g/s-km^2

The rates of respirable particulate emissions of each type (total, coal, and overburden) due to open mining of coal were calculated from Equation 4 for each of the 16 major surface mining states (j = 1 to 16) to arrive at the national loading. The resulting state and national mass emission rates from open coal mining are presented in Table 7. Coal dust is the major emission component, constituting 93% of the total emissions. The total respirable dust rate for open coal mining is 114 g/s.

Table 8 shows the respirable dust rate as compared with the total state and national particulate loadings. Open coal mining contributes more than 0.1% of each state's particulate emissions burden in Kentucky, North Dakota, West Virginia, and Wyoming; it contributes less than 0.1% of the burden in each of the remaining 12 states.

Table 9 shows the contribution to the national open coal mining rate from the various unit operations and windblown sources within surface mines. The unit operations of blasting, coal transport/unloading, and coal loading account for over 85% of the

TABLE 7. TOTAL EMISSION RATES OF RESPIRABLE DUSTS FROM OPEN COAL MINING BY STATE AND NATIONWIDE[a]

j	Location	Total dust, Q_{j1}, g/s, K=1	Coal dust, Q_{j2}, g/s, K=2	Overburden dust, Q_{j3}, g/s, K=3
1	Alabama	5.13	4.78	0.35
2	Arizona	1.18	1.09	0.09
3	Illinois	13.15	12.29	0.86
4	Indiana	9.39	8.84	0.55
5	Kentucky	25.07	23.39	1.68
6	Missouri	1.82	1.68	0.14
7	Montana	3.61	3.19	0.42
8	New Mexico	2.86	2.66	0.20
9	North Dakota	2.70	2.47	0.23
10	Ohio	15.88	12.58	3.3
11	Pennsylvania	10.55	9.78	0.77
12	Tennessee	2.15	1.98	0.17
13	Texas	1.70	1.54	0.16
14	Virginia	3.91	3.64	0.27
15	West Virginia	8.73	8.07	0.66
16	Wyoming	4.13	3.84	0.29
	Total	109.8	101.8	8.00
	Other states	4.26	4.0	0.26
	Nationwide	114.06	105.8	8.26

[a]Based on assumed emission rates.

TABLE 8. RATIO OF TOTAL EMISSION RATES OF RESPIRABLE DUSTS FROM OPEN COAL MINING TO TOTAL PARTICULATES, STATE AND NATIONWIDE[a]

j	Location	Total dust, %, K=1	Coal dust, %, K=2	Overburden dust, %, K=3
1	Alabama	0.013	0.012	0.001
2	Arizona	0.051	0.047	0.004
3	Illinois	0.036	0.034	0.002
4	Indiana	0.040	0.037	0.003
5	Kentucky	0.145	0.135	0.010
6	Missouri	0.028	0.026	0.002
7	Montana	0.042	0.037	0.005
8	New Mexico	0.088	0.082	0.006
9	North Dakota	0.108	0.099	0.009
10	Ohio	0.028	0.022	0.006
11	Pennsylvania	0.018	0.017	0.001
12	Tennessee	0.017	0.015	0.002
13	Texas	0.009	0.008	0.001
14	Virginia	0.026	0.024	0.002
15	West Virginia	0.129	0.119	0.010
16	Wyoming	0.173	0.161	0.012
	Nationwide	0.019	0.018	0.001

[a]Based on assumed emission factors.

emissions, while overburden stripping, reclamation, and coal augering account for less than 1% of the emissions of respirable dust.

TABLE 9. CONTRIBUTION TO RESPIRABLE MINING DUST EMISSIONS FROM EACH SOURCE WITHIN THE MINE[a] (percent of national mining total)[b]

Source	Coal dust	Overburden dust	Total dust
Wind erosion	1.6	1.6	3
Drilling	5.8	5.8	12
Overburden stripping	0	0	0
Coal loading	14	0	14
Coal transport and unloading	40	0	40
Blasting	30	0	30
Coal augering	1	0	1
Reclamation	0	0	0
National total	93	7	100

[a]Based on assumed emission factors.

[b]Data may not add to totals due to independent rounding.

The emission factors (E_i) were estimated from field data as was X_{Kj}. Coal production rates per state, P_j, are those given in Table 4 as reported by the United States Bureau of Mines (1). Values for state land disturbed annually by surface mining, A_j, were supplied in part by Paone, et al. (33), and partially by estimates made using the average coal stripping ratio per state and the associated production found in a recent United States Bureau of Mines report (34). Sample calculations and all input data are shown in Appendix C.

DEFINITION OF REPRESENTATIVE SOURCE

The representative surface coal mine is a single facility where 94% of the coal is mined via strip mining methods and 6% is mined via coal augering (U.S. average, see Table 4). All surface

(33) Paone, J., J. L. Morning, and L. Giorgetti. Land Utilization and Reclamation in the Mining Industry, 1930-1971. Bureau of Mines IC-9642, U.S. Department of the Interior, Washington, D.C., 1971. 148 pp.

(34) Strippable Reserves of Bituminous Coal and Lignite in the United States. Bureau of Mines IC-8531, U.S. Department of the Interior, Washington, D.C., 1971. 148 pp.

mining facilities have common methods of extracting coal from the ground; the sizes and amounts of equipment differ. It is therefore assumed that respirable dust emissions are directly proportional to the size of the mine.

The lack of heterogeneity within the surface coal industry indicates that a representative source may be defined by size of mine. Based on the 2,225 strip coal mines operating in the United States in 1972, the mean mine size was 108 x 10^3 metric tons/yr. The mean was chosen instead of the most frequently occurring size (i.e., the mode) for reasons which are illustrated in Figures 6 and 7. The frequency of occurrence of mines of the six defined size classes (U.S. Bureau of Mines) is shown in Figure 6. Of the 2,225 mines, 44% fall into the class yielding between 9 x 10^3 and 45 x 10^3 metric tons of coal per year. This class produced only 10.3% of the total surface coal as shown in Figure 7; 56% of the coal was produced by mines yielding more than 450 x 10^3 metric tons/yr. The mean size lies between these two extremes. Additionally, the mean size was chosen over the mode because the mines would become larger to offset the cost of control technology, should it be developed for surface coal mining. This would change the skewed distribution shown in Figures 6 and 7 into a more normal Gaussian distribution.

The representative source mine of 108 x 10^3 metric tons has unit operations to the extent predicted by the mean emission parameters indicated in Table 9. The distribution of average emissions within the industry is an indication of activity. Thus, 13% of the activity within the representative mine is devoted to drilling, and 13%, 38%, 32%, and 1%, are devoted to coal loading, coal transport/unloading, blasting, and coal augering, respectively. The average production weighted wind erosion emission factor calculated from data in Table 6 is 0.019 g/s · km^2 which indicates that the representative mine is located in either Illinois or Indiana.

The area of the representative mine is generally defined by its production rate, stripping ratio, and life expectancy. The representative mine has a life expectancy of 20 years based on averages compiled by the United States Bureau of Mines (35). The average stripping ratio is 13.6 m of overburden per meter of coal. A relationship was developed which computes the average mine size, expressed as:

$$A = 5.45 \times 10^{-8} \ (T)(P)(S_R) \qquad (5)$$

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(35) Coal Analyses of Model Mines for Strip Mining of Coal in the United States. Bureau of Mines IC-8535, U.S. Department of the Interior, Washington, D.C., 1972. 115 pp.

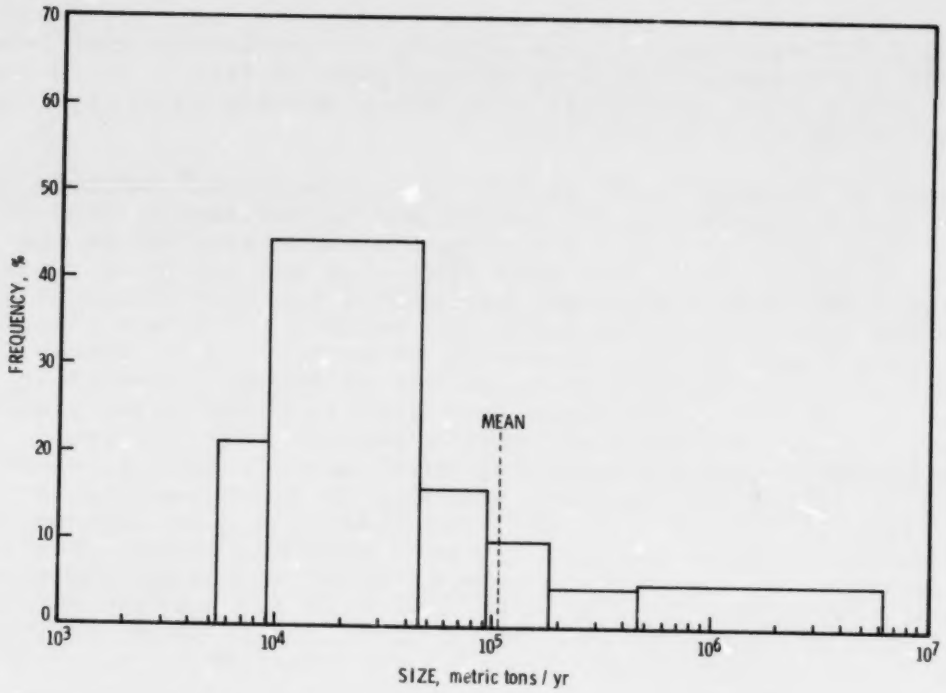

Figure 6. Surface coal mine size frequency distribution.

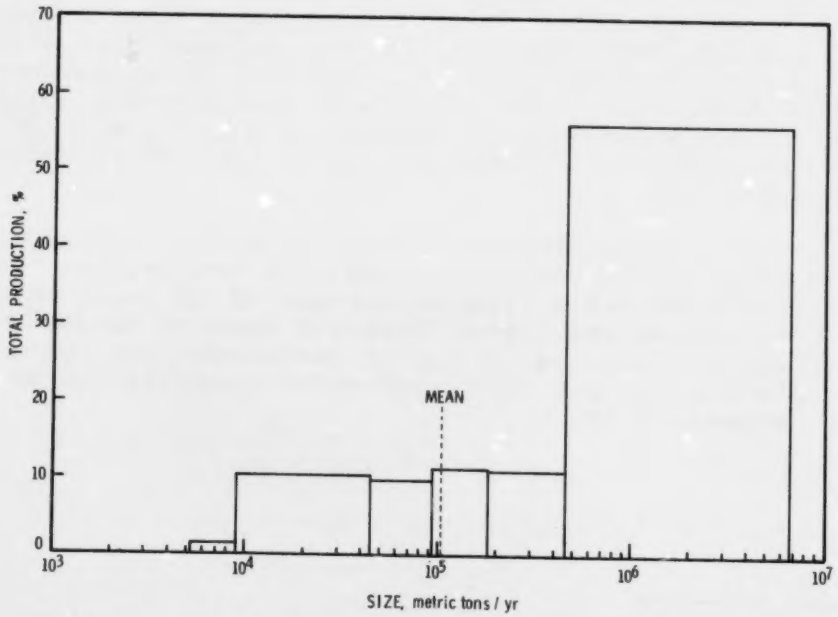

Figure 7. Surface coal mine production by mine size (1972 tonnage basis).

where A = total area of the mine, km^2
T = life expectancy, yr
P = average annual coal production, metric ton/yr
S_R = stripping ratio, m/m

The representative mine has an area of 2.0 km^2. The area mined per year by the representative mine is 98.5×10^3 m^2. Appendix C contains the derivation of Equation 5.

SOURCE SEVERITY

The maximum severity from the representative open coal mine was determined for each dust emission (coal, overburden, and total). The severity is defined as the time-averaged maximum ground level concentration of a pollutant ($\bar{\chi}_{max}$) divided by the primary standard, F. Using a severity model (36) based on Turner's dispersion model (37) and an average wind speed of 4.5 m/s and class C stability (U.S. average), the following equation was determined for total particulates from open sources:

$$S_p = \frac{\bar{\chi}_{max,\ p}}{F_p} = 4{,}020\ Q_p\ D^{-1.184} \qquad (6)$$

where S_p = total particulate (<7 μm) severity from open coal mining (dimensionless)
Q_p = emission rate of particulate from representative source, g/s
D = representative distance from source, m
$\bar{\chi}_{max,\ p}$ = time-averaged maximum ground level concentration of particulates, g/m^3
F_p = primary standard for particulates, g/m^3

The model for coal dust (less than 5% quartz) severity is expressed mathematically as (36):

$$S_c = 1.58 \times 10^5\ Q_c\ D^{-1.184} \qquad (7)$$

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(36) Blackwood, T. R. Final Report Outline of the Source Assessment Document. Contract 68-02-1874, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. (Report submitted by Monsanto Research Corporation, May 1975.) 16 pp.

(37) Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, 1969. 52 pp.

where S_c = coal dust severity from open coal mining (dimensionless)
Q_c = emission rate of coal dust from representative source, g/s

Finally, the model for overburden dusts containing free silica is (36):

$$S_o = 7.05 \times 10^5 \, Q_o \, D^{-1.814} \qquad (8)$$

where S_o = silica-containing overburden dust severity from open coal mining (dimensionless)
Q_o = emission rate of silica-containing overburden dust, g/s

Equation 7 was developed for coal containing the U.S. average of 3% free silica (TLV = 2 mg/m^3); Equation 8 was developed for overburden dust containing the U.S. average of 20% free silica (TLV = 0.44 mg/m^3).

The first estimate of severity was made at the physical boundaries of the representative mine where the severity is highest because of the inverse distance relationship. The representative source had an area of 2.0 km^2, and the representative distance to the boundary was 792 m. Equation 4 was used to compute the emission rates Q_p, Q_c, and Q_o where these were as follows:

$$Q_p = 0.0455 \text{ g/s}$$
$$Q_c = 0.0418 \text{ g/s}$$
$$Q_o = 3.70 \times 10^{-3} \text{ g/s}$$

The severities computed for total dust, coal dust, and overburden were 1.0×10^{-3}, 0.036, and 0.014, respectively.

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART

Emissions from open mining activities are generated from two sources, mining unit operations and wind entrainment. Air pollution at surface mines is a facet of the coal industry for which virtually no control technology or techniques have been established. Air pollution control, except for mine refuse piles, drills, and haul roads, has never been implemented.

Mine refuse piles are accumulations of wastes from the coal mining operation. These wastes contain carbonaceous material which is susceptible to spontaneous combustion. There are three methods of control: 1) removal of oxygen, 2) lowering of kindling temperature, and 3) removal of carbonaceous material. These methods of control are accomplished, respectively, by coating or otherwise shielding the pile from air currents, by applying cooling processes, and by cleaning the refuse to remove the carbonaceous matter. Piles are shielded from air currents by layer piling, piling with clay, sealing with clay and fly ash, digging out and backfilling, and using trenches for storage piles (38).

When pile fires occur they are extinguished by flooding, blanketing, slurry injection, compacting, loading out, and sealing. Water and bulldozers also have been used to isolate the burning sections. However, extinguishment can generate additional pollutants.

Drilling of blast holes using compressed air is an example of an equipment-related source of emissions. A variety of cyclones and baghouses are available for control of dust. Dust control during blasting is allied closely with control of the blasting practice. Well-planned, delayed shots will result in complete combustion of the explosives.

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(38) Maneval, R. R. Recent Advances in Extinguishment of Burning Coal Refuse Banks for Air Pollution Reduction. American Chemical Society, Division of Fuel Chemistry, Preprints, 13(2):27-41, 1969.

Emissions from wind entrainment are primarily generated from the loading and hauling of the coal and overburden. Rubber-tired equipment generates more dust than do crawler units. Asphalt mixtures are applied at some facilities for two reasons: to decrease the haulage time of the trucks and to suppress the dust. Most states enforce water spraying of haul roads to reduce dust and improve operator safety.

Stockpiles are a source of wind-entrained emissions at surface-mined sites. The size of these piles, however, is kept to a minimum, with coal loaded onto the transport units as soon as possible. Control techniques available are discussed in depth in the document entitled, "Source Assessment: Coal Storage Piles" (31).

FUTURE CONSIDERATIONS

Emissions from various sources in open mining may be controlled by applying the research and development of related areas. The "mechanical" dust created by the movement of equipment over the soil and coal, along with the dust generated by the loading and dumping of these materials, may be controlled by the application of a "chemical" spray (39). The chemical spray consists of a dilute water solution of a surfactant or other chemical agent. Water will not wet coal dust because of the difference in their surface tensions. If the surface tension of the water is reduced by addition of a surfactant or other wetting agent, it will then wet the dust. The spray solution is applied from headers directed over the source of the emissions. This technology may be applied to the travel and handling operations of the equipment; however, its cost-effectiveness in relation to open mining activities has not been studied.

Coal loaded in trucks may generate dust. This source has been controlled (40) by covering the material with tarpaulins or spraying with a chemical agent. The dumping operation emits additional dust which has been controlled through the use of enclosures placed over the dump area. Application of these control methods to open mining activities may also prove successful.

Wind entrainment generates fugitive dust from a variety of sources within the mine area. Control may be accomplished by good housekeeping procedures. Mine roads may be controlled by

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(39) No More Coal-Dust Problem for Georgia Power. Power, 105(7): 184-185, 1961.

(40) Minnick, L. J. Control of Particulate Emissions from Zinc Plants - A Survey. Journal of the Air Pollution Control Association, 21(4):195-200, 1971.

coating with either water or an emulsified asphalt (41). Asphalt should be used in areas where water may evaporate rapidly. Asphalt is usually applied to "out of the pit" roads since its effect on flotation and coal recovery may be adverse. Water spray trucks may work well in the pit area. Roadways have been coated with calcium chloride at underground mines, and this may work satisfactorily at surface mines. The construction of berms, the planting of suitable ground cover and windbreaks, erection of fencing, and minimum disturbance of vegetation can shield areas from wind entrainment (40). Cleaning of stripped rock by mechanical or hand sweeping has also been applied.

In general, however, control technology development has not been of serious concern to the surface mining industry.

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(41) Herde, R. S. Dust Control on Mine Roads. Mining Congress Journal, 51:90-92, July 1965.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

PRESENT AND EMERGING TECHNOLOGY

The popularity of any particular mining technique is illustrated by the "metric tons per man-shift" production level. In 1960, the average bituminous coal production was: 1) 20.8 metric tons/man-shift for strip mining, 2) 28.5 metric tons/man-shift for auger mining, and 3) 9.6 metric tons/man-shift for underground mining (16). The growth of open (surface) mining since 1920 is shown in Table 10.

TABLE 10. GROWTH OF SURFACE MINING (42)

Year	Total coal produced, 10^6 metric tons	Percent surface mined	Percent deep mined
1920	597.6	1.7	98.3
1930	487.1	4.2	95.8
1940	464.7	9.7	90.3
1950	508.4	24.1	75.9
1960	394.0	31.7	68.3
1970	555.7	43.9	56.1
1972	546.6	48.9	51.1

There are three basic methods of stripping coal (16). In the first, a single stripping shovel traveling on the exposed coal seam digs and removes the overburden ahead of it and piles it in the cut from which coal has previously been removed. In the second, a single dragline traveling on a bench above the coal strips overburden to widen the bench for its travel way for the next cut and removes the highwall bench over which it has traveled to expose the coal seam. In the third, a shovel and a dragline are used in tandem with both traveling on exposed coal. The shovel, working ahead of the dragline, removes the lower bench to expose the coal seam and piles the spoil in the cut from which

(42) Dials, G. E., and E. C. Moore. The Cost of Coal. Environment, 16(7):18-24, 1974.

coal has previously been removed. The dragline removes the upper portion of the overburden to form another bench and casts the spoil behind the shovel. Numerous combinations of shovels, draglines, bulldozers, scrapers, and other types of equipment are used throughout the industry. Stripping methods are discussed further in Appendix A.

There are two types of augering operations presently in use (16): 1) augering highwalls left by stripping operations, and 2) augering outcrop coal.

In planning an open mining activity, one of the first tasks is testing the material to determine its specific characteristics. Factors such as bank weight and volume (before excavation), loose weight and volume (after excavation), density, and swell factor are analyzed. Open mining operations then begin with the acquisition of the land based on prior knowledge of surface topography, overburden, seam characteristics, etc. Plant location is then influenced by access to transportation, sufficient area, refuse disposal sites, and shortest haulage distance to the cleaning plant. The economics of open mining are ultimately determined by the stripping ratio.

In mining coal, the value of the equipment used is directly related to its production potential. Machines are used to their maximum effectiveness since this increases the standard of production and decreases the manual labor costs. The machine that will provide the greatest production at the lowest cost will generally be the one selected for the job. Determination of the production potential is based on the type of material to be handled and the capabilities of the machine. Equipment characteristics such as struck capacity, nominal heaped capacity, and fill factor express the amount of material that the equipment container will hold. Material is generally classified as easy, medium, hard, and very hard, and the energy requirements of the equipment must be correlated with the material classification. These factors all govern the choice of the equipment described below.

Shovels

Shovels are used for the removal, dumping, and loading of overburden and/or coal. The shovel has evolved from a very crude device to a highly sophisticated piece of equipment. This has resulted from the continual improvement in design and adherence to the basic operating principles that resulted from the increased demand for production. The main concern, therefore, is the bucket, and everything is designed to promote its maximum effectiveness.

Power shovels are classified by the "struck" capacities of their buckets. Shovel buckets generally range in size from 14 m^3 to

107 m^3 (15). Every bucket size has a corresponding "depth of cut" which is the height of the material bank that will fill the bucket. Shovels presently available make it possible to mine deposits which could not previously be considered. To remove the material, a powerful steam or electric motor is needed. The larger shovels in use are generally electric or diesel-electric (43). Most of the recently purchased shovels are electric because they are more economical and convenient to use than are diesel-electric (44). Diesel-powered units are used where greater mobility is required.

A shovel has an average equipment capability of 83%, with the larger shovels being more efficient. Shovels are generally used where the material is too rough for other prime movers. They require little surface preparation, less labor, and exhibit a longer operating time than other equipment (15). The shovel works a cylindrical pattern of: 1) loading the bucket, 2) swinging to a dump point, 3) dumping the load, and 4) swinging back for the next cut (16).

Draglines

Draglines are also utilized for the removal, dumping, and loading of overburden and/or coal. They are designed to dig below the level of the machine and must be placed on solid ground (45). Draglines are used in the excavation of the "easy" to "hard" material classes of overburden. Smaller units are generally used for the loading of trucks since the larger units do not have loading preceision. Buckets of the larger draglines can cast the overburden at any point on a 6.28 rad circle.

As with shovels, dragline buckets are classified by their struck capacities. These bucket capacities range from 0.3 m^3 to 168 m^3. Draglines also follow a cylindrical pattern of: 1) dragging the bucket and filling, 2) hoisting and swinging to the dump point, 3) dumping the load, 4) lowering and swinging back the empty bucket, and 5) casting the bucket for the next load (15).

Today, electric motors are used on draglines because they provide greater power than other types, are easily controlled, and are economical. Diesel-electric engines are utilized when greater mobility is required. The smaller draglines rely solely on diesel power for mobility.

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(43) Marion Power Shovel Introductory Brochure. Marion Power Shovel Company, Marion, Ohio, 1968.

(44) Tractors and Scrapers Versus Shovels and Trucks. Mining Congress Journal. 52:42-45, January 1966.

(45) Carson, B. A. General Excavation Methods. F. W. Dodge Corporation, New York, New York, 1961. pp. 96-122.

Draglines have greater range and adaptability than other prime movers. They will dig deeper box cuts (greater overburden), can handle moist material, and are not restricted by the pit dimensions. Because of location outside of the pit, the dragline is not dependent on the floor quality and is safe from pit floodings or landslides (45).

The size of draglines doubled between 1954 and 1966. This trend is exemplified by the recent development of a dragline with a 168 m^3 bucket which weighs 24 metric tons (46).

Bucket Wheel Excavators

Wheel excavators are elaborate machines that can be used only in specialized situations. They are most successful in areas that do not require blasting. Excavators can work continuously below, above, or at the working level in tandem with belt conveyors which economically transport the material. This lowers the cost of the power required since it extends the discharge radius of the unit (15).

Wheel excavators are unsatisfactory for the following reasons: they exhibit a low operating efficiency; they have difficulty in handling hard materials; they require extensive surface preparation; and they have less flexibility than the draglines or shovels (15). In addition, they require a higher capital cost and demand a greater labor force than do other excavators.

Front-end Loaders

Front-end (F-E) loaders (see Figure 8) are used at almost all mining activities because of their production capability, versatility, and adaptability.

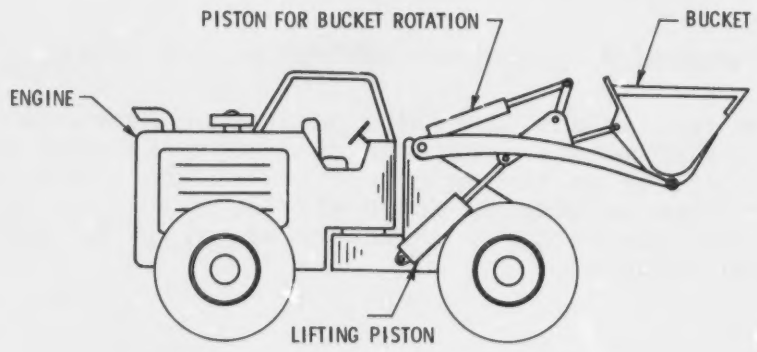

Figure 8. Front-end loader.

(46) Big Muskie: King of the Giants. Coal Age, 74(12):50-61 1969.

The F-E loader was originally a modified tractor with arms and a bucket attached, but it now has a specially designed frame. Steady improvements in design have corresponded with the acceptance of the F-E loader. It is well suited to the handling of stockpiled material or well-blasted rock. When equipped with rubber tires, it is an efficient haulage unit for short distances.

Bucket capacities range from 0.4 m^3 to 12.2 m^3. F-E loaders with buckets greater than 3 m^3 are all tire mounted. Crawler-mounted units are used on difficult surfaces, but they are slow moving and are used to transport material only over short distances. The rubber-tired units are faster and more agile.

Scraper

Scrapers (see Figure 9) are available in a variety of designs and capacities that can be used in any mining system. They are generally used for handling material in refuse or stockpiles (47). Scrapers are presently available in four models: hoe, box, crescent, and folding (48). The digging and hauling qualities of a unit are functions of its weight, blade curvature, and harnessing of the rope pull which is the only adjusting piece of equipment on the machine.

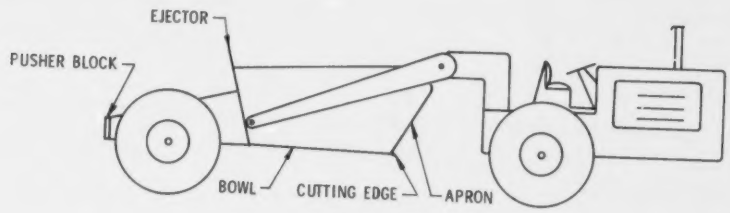

Figure 9. Scraper (self-propelled unit).

Scrapers are used as auxiliary equipment when overburden is to be moved hundreds of meters. This is done when the soil is loose or relatively soft, as in the upper portion of the overburden. Scraper operation is complex and cyclical, requiring the coordination of man and machine. Scrapers are rated by their struck and/or heaped capacity.

(47) Young, G. I. Elements of Mining. McGraw-Hill Book Company, New York, New York, 1946. 414 pp.

(48) Wetson, J. A. Guide to the Selection of Mine Scrapers. Engineering and Mining Journal, 168:173-175, January 1967.

The selection of a scraper depends on the type of tractor that will pull the unit. The self-propelled unit shown in Figure 9 provides vastly improved haulage speeds. Four-wheel drive units are the newest innovation. They can be used on steeper grades and they provide greater pulling power than do the older types.

Bulldozers

A bulldozer (see Figure 10) is also an evolution of the tractor, with a curved steel blade attached to the front by pivotal arms. The blade can be lowered, raised, or tilted by means of adjoining cables or rams.

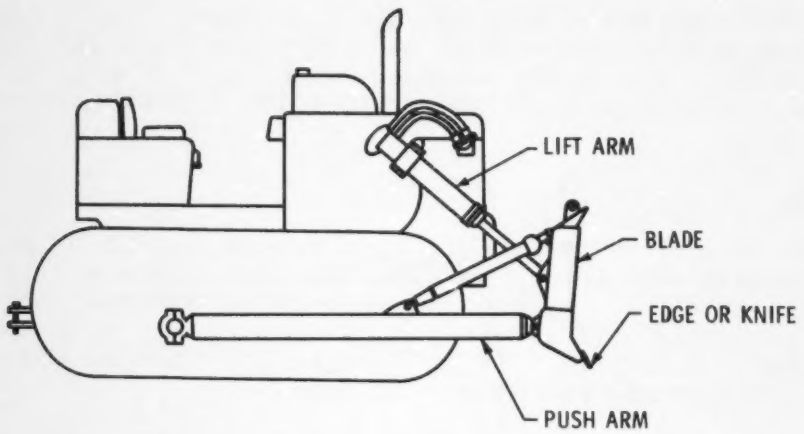

Figure 9. Scraper (self-propelled unit).

Bulldozers are currently used for numerous activities such as land clearing and preparation, maintenance and clearance of haulage roads, cleanup for shovels and draglines, maintenance of spoil piles, ripping and stump removal, and various other stripping activities (49). Dozers are generally used when the soil does not have to be pushed more than 100 m.

There are six types of dozers on the market: 1) straight bulldozers, 2) angle dozers, 3) tilt dozers, 4) push dozers, 5) U-shaped dozers, and 6) other modifications (50). The main controlling factor in the selection of equipment is the condition and type of material being excavated. Dozers are available with

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(49) Warren, P. J. Tractor Dozers Blaze the Trail. Rock Products, 66:84-86, 94-96, March 1963.

(50) Adler, Y., and H. E. Naumann. Analyzing Excavation and Materials Handling Equipment. Research Division Bulletin No. 53, Virginia Polytechnic Institute, Blacksburg, Virginia, February 1970. 230 pp.

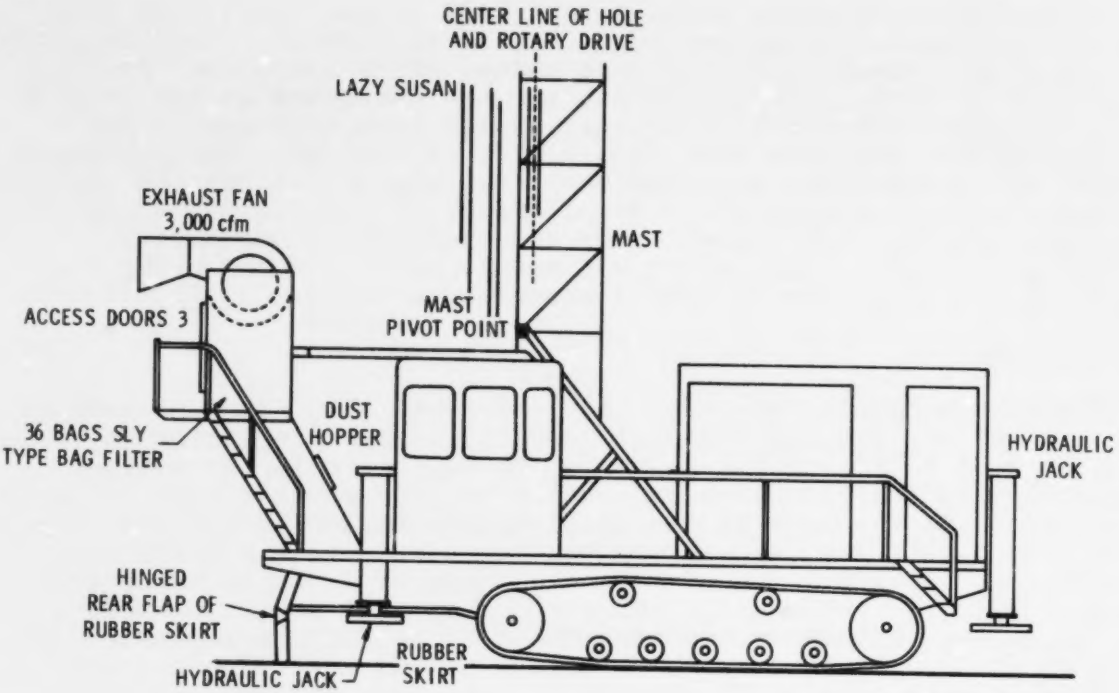

Figure 11. Rotary drill with dust control equipment (54).

The newer method of inclined drilling is gaining wider acceptance in the industry due to its greater toe and back breakage, better fragmentation, use of fewer explosives/metric ton small diameter of holes required, and greater overburden throwing distances (16).

Automation of drills to speed up the process, to keep pace with the increased tempo of mining production, has met with limited success (55). Development of such drills is particularly needed because of the lack of skilled manpower available for operation of the drills presently in use.

Haulage Equipment

The size of haulage units may vary over a large range since the units are matched to the capacity of the loading rigs. A general rule of thumb in the industry is to use trucks having a capacity which is four to five times that of the dipper capacity of the loading units.

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(55) Li, T. M. Rotary Drilling with Automated Controls - New Force in Open-Pit Blast Hole Production. Coal Age, 79(8): 82-89, 1974.

In applications where haulage roads are steep, individual electric drives are sometimes connected to each wheel. Engines up to 522 kW are common among haulage units, which are diesel powered. Over the years, the cost of haulage has decreased as the size of haulers and the quantity of coal hauled have increased. Fuel consumption averages more than 1.85×10^{-3} m^3/km. The increased use of tandem-drive axle and dual rear wheels has cut the costs and increased production. In addition, the use of paved haul roads has cut down travel times and increased productivity. Larger haulage units, up to 200 metric tons, are now being utilized, and the trend is toward even larger units.

Blasting

The most commonly used blasting explosive, ANFO, is a mixture of ammonium nitrate and fuel oil, usually in the proportion of 454 kg of NH_4NO_3 to 2.2 kg to 2.7 kg of fuel oil. At smaller facilities the explosive is usually bagged, and the fuel oil is poured over the bags at the drill site. Larger facilities have mixing plants and the mixture is transported to the drill site where it is either poured into the holes or blown in using compressed air. Pneumatic loading of horizontal drill holes is a new technique that may replace the need to hand or mechanically tamp the charge (56). The holes are spaced according to their size, the overburden thickness, and the type of rock.

A slurry blasting agent of ammonium nitrate, sodium nitrate, a high explosive sensitizer, and water has recently been developed which may replace ANFO.

INDUSTRY PRODUCTION TRENDS

Coal Development

The trend in the coal industry is to increase the open mining proportion of production. The introduction of multiple-headed augers has increased the production rate of auger mining. The use of the "haulback" method of strip mining has made this method of extraction more environmentally acceptable. With over 70% of the nation's coal reserves lying in the western states, the growth for this region is anticipated to extend into the 21st century. Conventional equipment will be used to mine these reserves, but it will require larger booms for greater spoil reach.

With coal reserves growing, the demand for larger capacity mining units has increased. Larger units are being introduced each year

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(56) Murray, J. R., and J. W. Francis. Consol Tries Pneumatic Bulk Loading of Horizontal Drill Holes. Coal Age, 79(1): 64-65, 1974.

to cope with the increased amounts of rock and dirt that must be removed. Despite the higher cost of larger units, the overall cost for mining a cubic meter of overburden with them is lower than that of the smaller machinery. Thus, over the years, the average depth of overburden removed to expose coal seams will steadily increase. Since most western coals are relatively low in sulfur content and occur in thicker seams than in the east, this area has become more environmentally and economically attractive.

Growth Factor

The total annual surface coal production predicted for 1978 is 312×10^6 metric tons based on projections made by the National Petroleum Council in 1973 (57). This forecast assumes a sustained growth rate of 3.5% per year. The emissions are expected to increase in proportion to the growth due to the assumed lack of further control technology implementation. The growth factor, defined as the ratio of 1978 emissions of respirable dust to 1972 emissions of respirable dust, is 1.23.

(57) U.S. Energy Outlook - Coal Availability. A Report by the Coal Task Group of the Other Energy Resources Subcommittee of the National Petroleum Council's Committee on U.S. Energy Outlook, Washington, D.C., 1973. p. 287.

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APPENDIX A

STRIP AND AUGER MINING TECHNIQUES FROM THE STANDPOINT OF REGIONAL VARIABILITY

Strip (opencast) mining and auger mining are the two methods most widely used for removing surface coal.

Strip mining consists of removing the overburden, extracting the coal, and then replacing the overburden. When the overlying material consists of earth or clay, it can be removed directly by scrapers or excavators, but where rock is encountered it is necessary to resort to blasting to prepare the material for handling by the excavators. The usual method of working is to extract the coal in a series of regular slices called cuts. The length of each cut is governed by the limits of the area to be worked. The width of the cut depends on the type of excavating equipment available; for example, in the case of dragline excavators the casting distance will be a determining factor. The first operation is to make an initial cut, called the box cut, into solid ground. Overburden from this cut has to be loaded into vehicles and transported to a suitable dumping ground. The exposed coal can then be excavated. Next, the overburden of the second cut is deposited into the void of the preceding cut, thereby exposing a fresh area of coal for excavation. This system is repeated across the area to be worked, and the box cut overburden is used to fill the void of the final cut (2).

Auger mining is a method often used by strip mine operators when the overburden gets too thick to be removed economically. Large-diameter, evenly spaced holes are drilled up to 61 m into the coalbed by an auger. Like a bit used for boring holes in wood, this consists of a cutting head with screwlike extensions. As the auger turns, the head breaks the coal, and the screwlike extensions raise it and dump it on an elevating conveyor; this, in turn, carries the coal to an overhead bin or loads it directly into a truck. Auger mining is relatively inexpensive, and it is reported to recover approximately 60% to 65% of the coal (2).

There are two broad strip coal mining techniques practiced in the United States, contour mining and area mining. Both types can be used only if the overburden thickness is less than approximately 61 m (the limit of current equipment). Contour mining finds application in hilly terrain where the topography governs pit design. The objective of contour mining is to extract coal by

excavating narrow strips which follow the circumference of the hill. Coalbeds generally lie flat in the ground; thus it is impractical to completely extract coal lying in a hillside. The overburden becomes increasingly deeper, resulting in uneconomical extraction. This fact can be readily seen in Figure A-1 (58).

The term maximum stripping ratio is used to determine where mining becomes uneconomical. Stripping ratio is usually defined as the ratio of the depth of overburden removed to depth of coal produced (meters of overburden/meter coal). Thus, large amounts of overburden are commonly removed if the coal seam is thick, as shown in Figure A-1. The maximum stripping ratio varies from region to region, but 20:1 is a typical figure. At one Illinois mine as much as 24 m of overburden is stripped to recover 71 cm of coal (16).

Area mining, the second general method of strip mining, involves the development of large flat open pits in a series of long narrow strips, usually 30 m wide by 1 km or more in length. The objective of area mining, which also applies to contour mining, is to expose, recover, and haul away the coal as economically as possible. This usually means that the overburden should be moved only once. The above definition of stripping ratio holds identically for area mining. A generalized schematic representative of open pit or area mining at an Illinois mine is shown in Figure A-2. This schematic depicts a dragline working a multiple coal seam operation. The view of a Wyoming mine in Figure A-3 shows two seams being worked from an upper and a lower bench. Regional variations exist in strip mining (58), and the three divisions of East and Mideast, Central, and Midwest and West can be used to classify these variations as described below.

East and Mideast

The East is characterized by steep, hilly topography with the coal outcropping on both sides of the hills. Strip mining is generally confined to small tracts of land, and because of the nature of the terrain, contour mining with small equipment is more common than area mining (58).

The Mideast is also noted for hilly terrain, although the slopes are not as steep as those encountered in Pennsylvania. Contour mining is generally the rule, especially in Ohio, and variations from mine to mine concern the amount of land affected as one

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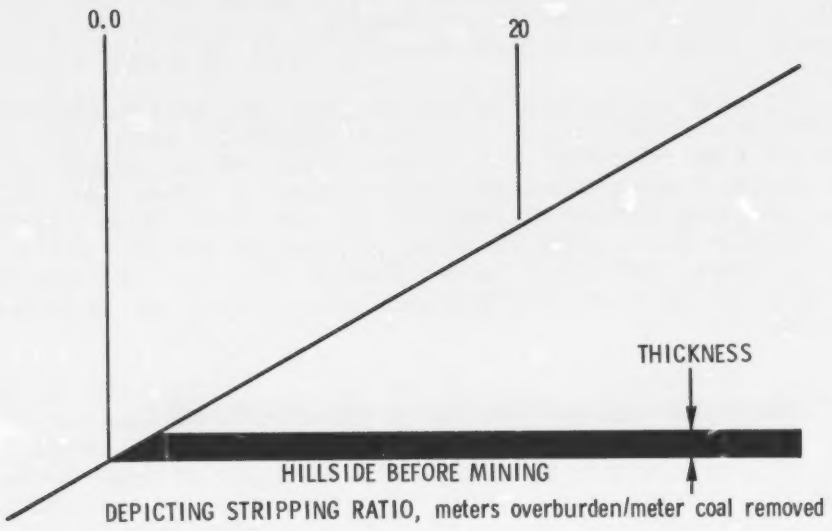
(58) Stefanko, R., R. J. Ramani, and M. R. Ferko. An Analysis of Strip Mining Methods and Equipment Selection. Office of Coal Research R&D Report No. 61, Interim Report No. 7, U.S. Department of the Interior, Washington, D.C., 29 May 1973. 131 pp.



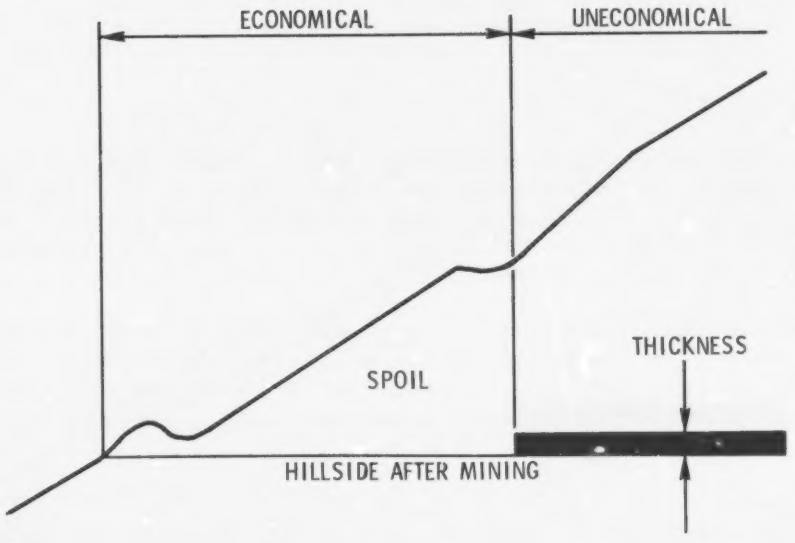
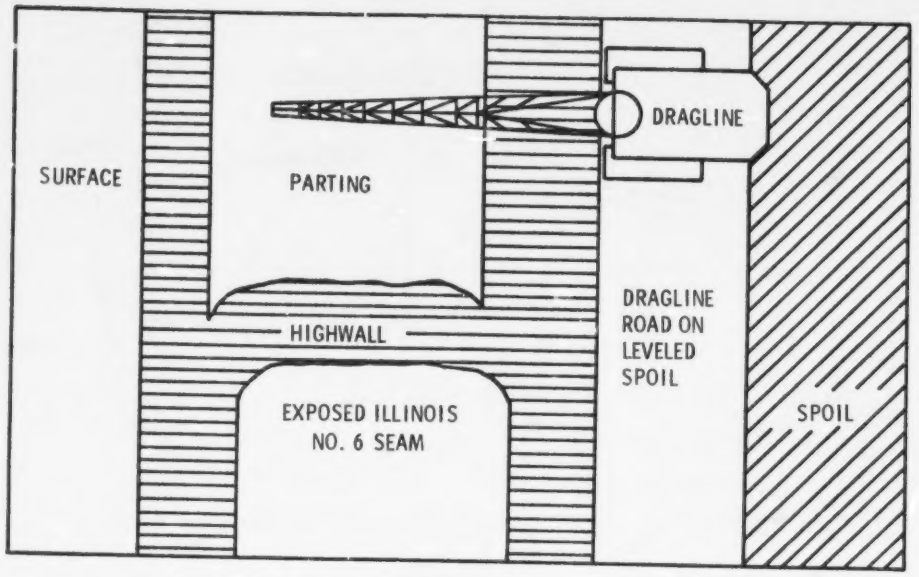
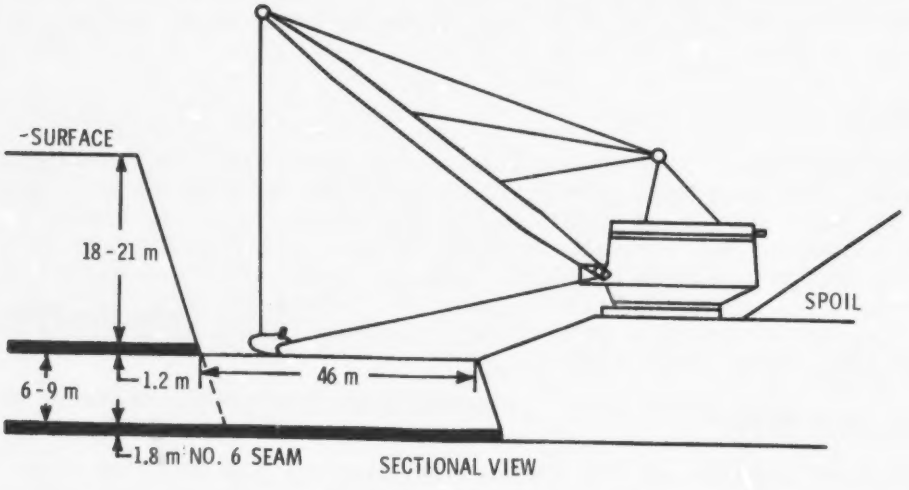


Figure A-1. Hillside before and after mining showing typical stripping ratio variability (58).



PLAN VIEW



SECTIONAL VIEW

Figure A-2. Dragline positioned on leveled spoil removing parting for multiple seam operation in Illinois (58).

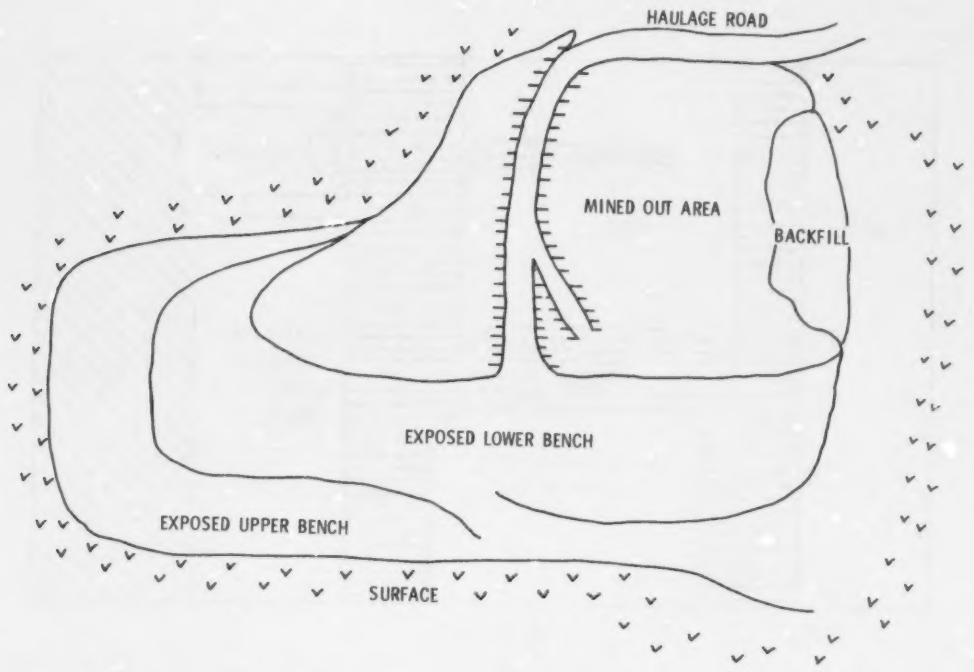


Figure A-3. Plan view of a Wyoming open pit coal mine (58).

tract and the equipment size used. In this area equipment with capacities up to 164 m^3 is used to mine coal from seams at depths up to 56 m (58).

Central

As the topography of the land becomes more flat in the Central region of the country, the mining methods become more traditional. The pits are nearly straight for their entire length. Different kinds of equipment such as bucket wheel excavators find rather widespread use in this area because of the unconsolidated nature of the upper strata. In other areas of the Central region where the upper strata are consolidated, large draglines are utilized to mine coal (58).

Midwest and West

The Midwest region of the United States is the western portion of the Great Plain, specifically the states of North and South Dakota. The topography of this area is nearly flat, and although no surface mining is currently under way in South Dakota, ample lignite reserves are present for future development (58).

The topography of the West is characterized by gently rolling hills which gradually steepen toward the Rocky Mountains. The coal seams are generally subbituminous and lignite. Small capacity equipment is utilized to mine these coals. The most striking characteristic of the coal seams in this region is their thickness, which approaches 31 m in some areas (58).

APPENDIX B

RESPIRABLE DUST EMISSION FACTOR DERIVATION AND SUPPORTIVE DATA

UNIT OPERATIONS

The emission factors for open coal mining were arrived at by field sampling two mines. Information on overburden dusts resulting from drilling, overburden removal (stripping), and blasting was obtained from mine A, a bituminous coal mine located in Illinois. Mine B, a subbituminous coal mine located in Wyoming, was sampled for information on coal dusts resulting from blasting, transport/unloading, and loading.

The field measurements were made on a portable respirable dust monitor manufactured by GCA Corporation, Model RDM 101-4. When employed in the respirable "mode" the instrument measures mass concentrations of particles having mean diameters (assumed spherical) less than 7 μm. The instrument is capable of measuring dust concentrations ranging from 20 $\mu g/m^3$ to 10 x 10^3 $\mu g/m^3$. The accuracy of the instrument is defined in its specifications as "...within ±25% of the measurements obtained from a companion simultaneous gravimetric respirable mass sample for 95% of the samples."

The general procedure for determining the respirable dust emission factors consisted of sampling the equipment actively engaged in mining for mass concentrations, computing an emission rate via one of Turner's (37) Gaussian plume models (point source, line source, dose), and finally relating the emission rate to pertinent weighting parameters. The weighting parameters were used to convert the mass emission rate to mass emissions (g) per metric ton of coal mined in the case of the unit operations. The specific weighting parameters used are discussed in this section.

The three-diminsional coordinate system describing the location of the GCA sampler with respect to the emission source is depicted in Figure B-1 for point sources. The GCA sampler was elevated downwind approximately 2 m above ground in all instances to minimize ground effect. Care was taken to ensure that the plume was not missed when sampling at x distances less than 100 m by choosing elevated sites. A rule of thumb generally used to set the minimum sampling distance was that the sampler be set a distance x that is greater than 18 times z, the effective height

of the emission source (from the sampler datum). The mass concentration contribution of the source was estimated as the difference between the downwind reading and the background reading. Background readings were obtained by sampling with the GCA monitor at the mine boundaries furthest upwind.

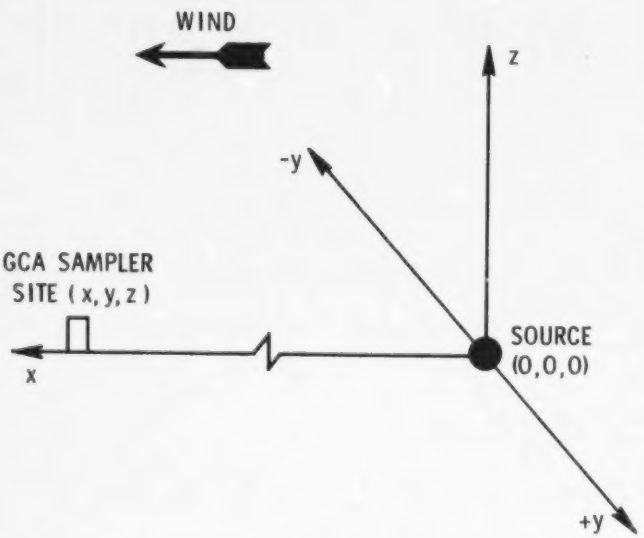


Figure B-1. Three-dimensional rectangular coordinate systems (point sources).

The raw concentration data from mines A and B are presented in Table B-1. The results indicate that draglines and overburden blasting operations do not emit significant quantities of respirable dust, although much visible dust was witnessed. Overburden stripping is performed by several types of equipment throughout the industry, but the functions of each type are similar and thus the emission factor for overburden stripping was assigned a zero value. The overburden blasting did not emit respirable particulates; the coal blasting operation at mine B did. This suggests a greater friability of coal versus overburden. Drilling operations generated the highest concentrations of dust. Of all unit operations, drilling comminutes the particles of greatest amount, especially in tough overburden (rock). Coal drilling operations were not sampled because they are not as widely used throughout the industry as overburden drilling.

The unit operations of reclamation and coal augering were also not sampled. The reclamation operation is similar in nature to overburden stripping and perhaps less severe. Thus, an emission factor of zero was assigned to it. Coal augering generates respirable dust that is expected to be similar in magnitude to that

TABLE B-1. RAW DATA - UNIT OPERATIONS

Unit operation	Date	Atmospheric stability	Wind speed, m/s	Distance, m			Dust type	Downwind conc., $\mu g/m^3$	BGD, $\mu g/m^3$	X, $\mu g/m^3$	Comments
				x	y	z					
Overburden stripping	4/16/75	C	3.0	117.9	0	15.2	Overburden[a]	<50[b]	28.8	0	Bucyrus-Erie 1450-W 60-yd^3 dragline.
				101.2	0	15.2	Overburden[a]	<50[b]	28.8	0	
				70.7	0	15.2	Overburden[a]	<50[b]	28.8	0	
				87.5	0	15.2	Overburden[a]	<50[b]	28.8	0	
				87.5	0	15.2	Overburden[a]	<50[b]	28.8	0	
				152.4	0	0	Overburden[a]	<50[b]	28.8	0	
Drilling	4/17/75	D	9.0	33.5	0	0	Overburden[a]	930.0	28.8	901.2	Bucyrus-Erie 61-R 15-in-diam. drill (no control).
				33.5	0	0	Overburden[a]	2,030.0	28.8	2,001.2	
				33.5	0	0	Overburden[a]	1,120.0	28.8	1,091.2	
				33.5	0	0	Overburden[a]	2,130.0	28.8	2,101.2	
Blasting	4/18/75	D	9.8	260.0	0	0	Overburden[a]	0.0[b]	28.8	0.0	9,107 kg ANFO detonated (twelve-55-ft holes) (4-min sample).
Blasting	5/15/75	B	4.47	76.2	0	-12.2	Coal[c]	490	10[b]	480.0	196 kg ANFO (4-min sample).
				457.2	30.5	30.5	Coal[c]	140.0	0[b]	140.0	536 kg ANFO (4-min sample).
				76.2	9.1	-12.2	Coal[c]	70.0	0[b]	70.0	Approx. 27 metric tons coal loaded into truck by 750-metric ton per hour front-end loader.
Loading	5/15/75	B	5.4	76.2	0	0	Coal	283.0	10	273.0	91 metric tons loaded into truck in 5 min.
				76.2	0	0	Coal	388.0	10	378.0	91 metric tons loaded into truck in 6 min.
				76.2	0	0	Coal	204.0	10	194.0	
Transport	5/15/75	B	2.2	22.9	0	0	Coal	480.0	20.0	460.0	12.9 km/hr transport (0.524 rad angle, unwatered road).
Transport	5/15/75	B	3.6	15.2	0	0	Coal	1,280.0	0[b]	1,280.0	Unpaved road, 1 truck
				54.9	4.6	0	Coal	320.0	0[b]	320.0	36.6 m of transport, 1 truck.
Unloading	5/15/75	B	4.47	76.2	0	0	Coal	440.0	10	430.0	One 91-metric ton truck unloading on unwatered road.
				76.2	0	0	Coal	210.0	150[d]	60.0	One 91-metric ton truck unloading on watered road.

[a] Mine A.

[b] Below detectable limits.

[c] Mine B.

[d] Background is for one truck on a watered road, no unloading.

measured for drilling. The emission factor for coal augering is obtained from the emission factor from drilling, with an appropriate correction factor applied.

Point Source

To arrive at the emission factors the emission rates must first be obtained from the raw data. Turner's Gaussian diffusion point source model (37) given below in general form was utilized in the case of the unit operations of loading, drilling, and unloading:

$$Q = 4\chi\pi\sigma_y\sigma_z u e^{\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} e^{\frac{1}{2}\left(\frac{z}{\sigma_z}\right)^2} \qquad \text{(B-1)}$$

where Q = emission rate, g/s
χ = concentration contribution of a unit operation, g/m^3
σ_y = lateral dispersion coefficient
$\sigma_y = Ax^{0.9031}$ where A is a stability constant
σ_z = vertical dispersion coefficeint
$\sigma_z = AX^B + C$ where A, B, and C are stability constants
u = wind speed, m/s

Line Source

The unit operation of transport was estimated by assuming that the emissions from the vehicles resemble a continuously emitting infinite line source with the angle between the wind direction and line source being ϕ. The model is Gaussian and is expressed as (37):

$$q = \frac{1}{2}\sin\phi\sqrt{2\pi}\ \sigma_z u\chi e^{-\frac{1}{2}\left(\frac{z}{\sigma_z}\right)^2} \qquad \text{(B-2)}$$

where q = source strength per unit distance, g/s-m

Total Dosage from a Finite Release

The blasting unit operation mass emission was estimated as a total release integrated over the time of passage of the blast. This release of mass is expressed as follows (37):

$$Q_T = D_T\pi\sigma_y\sigma_z u e^{\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} e^{\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2} \qquad \text{(B-3)}$$

where Q_T = total release, g
D_T = total dosage, g-s/m^3
$D_T = \chi t_s$ where t_s is the total sampling time, s

The calculated values of Q, q, and Q_T are presented in Table B-2.

TABLE B-2. MASS EMISSIONS[a]

Unit operation	Date	Model	$\chi \times 10^6$ g/m^3	$D_t \times 10^6$ g-s/m^3	Q, g/s	q, g/s-m	Q_T, g
Drilling	4/17/75	Point	901.2		0.16		
			2,001.2		0.35		
			1,091.2		0.19		
			2,101.2		0.36		
Blasting	5/15/75	Dose	480.0	115,200			531.0
			140.0	33,600			1,841.0
Loading	5/15/75	Point	70.0		0.483		
			273.0		0.537		
			378.0		0.744		
			194.0		0.382		
Transport	5/15/75	Line	460.0			0.00307	
			1,280.0			0.01108	
			320.0			0.00905	
Unloading	5/15/75	Dose	430.0	103,200			169.2
			60.0	14,400			23.6

[a]Blanks indicate data not applicable.

Since the equipment sampled was typical of the industry, the mass emissions per equipment type were converted to emission factors for use in describing the industry contribution. The following describes the conversion of the mass emissions per unit operation to workable emission factors using appropriate weighting factors.

Drilling Overburden

$$Q = 0.35 \text{ g/s}$$

At mine A, it takes 45 min to drill 16.8 m or 6.2×10^{-3} m/s.

Thus,

$$\frac{0.35 \text{ g}}{\text{s}} \times \frac{1 \text{ s}}{6.2 \times 10^{-3} \text{ m}} = \frac{56.4 \text{ g dust}}{\text{meter of hole}}$$

To estimate the g/metric ton of coal mined, we must estimate the amount of ANFO per metric ton of coal mined and the ANFO packing per hole. From annual Illinois state statistics on surface coal production and ANFO usage, we obtain (1, 17):

$$\frac{52.7 \times 10^6 \text{ kg ANFO}}{30.7 \times 10^6 \text{ metric tons coal}} = \frac{1{,}716.6 \text{ g ANFO}}{\text{metric ton coal}}$$

Mine A uses 46,039.1 g ANFO/m; thus,

$$\frac{56.4 \text{ g dust}}{\text{m}} \times \frac{1 \text{ m}}{46{,}039.1 \text{ g ANFO}} \times \frac{1{,}716.6 \text{ g ANFO}}{\text{metric ton coal}} = \frac{2.10 \text{ g dust}}{\text{metric ton coal}}$$

Similarly, for the other three data points, the emission factors are:

For #2: 1.14 g dust/metric ton coal
For #3: 0.962 g dust/metric ton coal
For #4: 2.16 g dust/metric ton coal

The average drilling emission factor is 1.59 g/metric ton of coal with a standard deviation of 0.628.

Transport of Coal (Unwatered Road)

1. 0.00307 g/m-s - one 91-metric ton truck at 3.58 m/s, 4-min sample

   or 0.738 g/v-m

2. 0.01108 g/m-s - one 91-metric ton truck at 2.23 m/s and one pickup truck at 4.47 m/s, 4-min sample

   or 1.33 g/v-m

3. 0.00905 g/m-s - one 91-metric ton truck at 3.58 m/s, 4-min sample

   or 2.17 g/v-m

avg.: 1.41 ±0.720 g/v-m

Since the representative mine has an area of 1.97 km^2, the distance for transport is a maximum of 700 m. Thus,

$$1.41 \text{ g/v-m } (700 \text{ m})\left(\frac{\text{vehicle}}{91 \text{ metric tons}}\right) = 10.85 \text{ g/metric ton}$$

In a representative mine the road is watered to reduce this dust. The sampling results show that over a 50% reduction is achieved through watering (200 $\mu g/m^3$ on watered road vs. 430 $\mu g/m^3$ on unwatered road; same distance, wind speed, etc.). Thus, the emission factor for a watered road would be

10.85 g/metric ton (0.465) = 5.04 g/metric ton

Blasting Coal

Floor (1.81 kg ANFO/metric ton): 4.06 g/metric ton
Wall (1.23 kg ANFO/metric ton): 4.24 g/metric ton
avg.: 4.15 ±0.127 g/metric ton

Loading Coal (Including 30-m Transport and Payloader)

115.9 g ÷ 29.9 metric tons (1/3 truck) = 3.87 g/metric tons
225.6 g ÷ 91 metric tons (5 min) = 2.487 g/metric tons
312.4 ÷ 91 metric tons (6 min) = 3.444 g/metric ton
160.3 ÷ 91 metric tons (6 min) = 1.767 g/metric ton
avg.: 2.89 ± 0.947 g/metric ton

Loading Coal (Corrected to Exclude Transport)

2.89 - (1.41 g/v-m x 3.0 m/91 metric ton) = 1.96 g/metric ton
±1.42

Unloading Coal (Including 40-m Transport)
(unwatered road)

169.2 g ÷ 91 metric tons = 1.865 g/metric ton

Unloading Only

1. 1.865 - 1.24 = 0.625 g/metric ton

2. 23.6 g ÷ 91 metric tons = 0.260 g/metric ton

avg.: 0.442 ± 0.257 g/metric ton

The emission factors are summarized in Table B-3. Coal augering is similar to drilling. The weighting parameter used to derive the representative factor was the ratio of annual auger production to annual strip coal production for 1972. This is not a statistically derived value and as such no error estimate can be made for it. All factors are expressed in grams of respirable dust emitted per metric ton of raw coal produced.

TABLE B-3. EMISSION FACTORS[a]
(grams of respirable dust/metric ton of raw coal)

Operation	Sample #1	#2	#3	#4	Average ± standard deviation
Drilling	2.10	1.14	0.962	2.16	1.59 ± 0.628
Transport[b] (dry load)	0.738[c]	1.33[c]	2.17[c]		(1.41 ± 0.72)[c]
Blasting	4.06	4.24			5.04 ± 2.57
Loading coal (inc. trans.)	3.87	2.49	3.44	1.77	4.15 ± 0.127
(exc. trans.)					(2.89 ± 0.947)[d]
Unloading coal (inc. trans.)	1.865[d]				1.96 ± 1.42
(exc. trans.)[b]	0.623	0.260			0.442 ± 0.257
Coal augering					0.084

[a]Blanks indicate data not applicable.

[b]Added together to arrive at a factor for transport/unloading.

[c]Units are grams of respirable dust/vehicle-meter, used to derive factor in grams/metric ton of coal.

[d]Only used to derive the exc. trans. factor.

WIND EROSION - WORST CASE

The Woodruff-Siddoway (W-S) equation was solved by nomograph to arrive at the emission factors for wind eroded land (19). The factors were calculated for each coal state. The W-S equation describes the amount of total dust emitted. This includes respirable dust and dust via saltation, which is large particle dust (greater than 7 μm). As a result, the emission factor estimates for wind erosion are higher than those for respirable dust alone. The emission factors are thus a worst case estimate. The assumptions used when calculating the wind erosion emission factors are listed below:

- Assume no ridges (K = 1)
- Assume no vegetation (V = 0)
- Deviation of percent soil cloddiness based on:
  1. descriptions of soil types found in various states; i.e., loam, sandy loam, clay, etc.
  2. typical particle-size distributions of various types of soil.
  3. based on these two situations, the average for a particular state was derived. For example, a very general estimate was made

that North Dakota is 1/6 sandy loam, 1/2 silt loam, 1/6 sand, and 1/6 clay.

Percent soil fractions larger than 0.84 mm in North Dakota = 1/6 (particles >0.84 mm in sandy loam) + 1/2 (particles >0.84 mm in silt loam) + 1/6 (particles >0.84 mm in sand) + 1/6 (particles >0.84 mm in clay).

The above information was then used to solve the W-S equation.

APPENDIX C

INPUT DATA, DERIVATIONS, AND SAMPLE CALCULATIONS PERTAINING TO MASS EMISSION RATES AND REPRESENTATIVE SOURCE DEFINITION

MASS EMISSIONS

The work sheet for Equation 4 is presented in Table C-1. The parameters and units of each are given below:

A_j = state areas of land disturbed annually, km^2

e_j = state emission factor for wind erosion, g/s-km^2

P_j = state coal production for 1972, metric tons/yr

ΣE_i = sum of the appropriate emission factors per state;

- ΣE_i = 13.3 for all six unit operations, g/metric ton
- ΣE_i = 13.2 for states not having coal augering operations, g/metric ton

Q_{j1} = total respirable dust mass emissions per state from open coal mining, g/s

Q_{j2} = respirable coal dust mass emissions per state, g/s

Q_{j3} = respirable overburden dust mass emissions per state, g/s

Percent ratios are obtained by dividing Q_{j1}, Q_{j2}, and Q_{j3} by total particulates per state (dimensionless).

The composition of dust emitted from the industry was estimated to contain 93% coal and 7% overburden dusts. This was estimated by considering the dust composition from the unit operations and wind erosion. Overburden stripping and reclamation are not included as their respirable dust hazard is negligible (see Appendix B). The breakdown is shown in Table C-2.

TABLE C-1. INPUT DATA AND COMPUTATIONS FOR DETERMINING STATEWIDE MASS EMISSIONS[a]

$$Q_{jk} = A_j e_j x_k + 3.171 \times 10^{-8} P_j x_k \sum_{i=1}^{6} E_i$$

j	State	A_j	$e_j \times 10^3$	$A_j e_j$	$P_j \times 10^{-3}$	ΣE_i	$3.171 \times 10^{-8} \times P_j \Sigma E_i$	Q_{j1}[b]	Q_{j2}[c]	Q_{j3}[d]	Total particulate (all sources), g/s (59)	Ratio$_{total}$[b]	Ratio$_{coal}$[c]	Ratio overburden[d]
1	Alabama	11.675	7.47	0.087	11,988	13.27	5.04	5.13	4.73	0.35	37,370	0.013	0.012	0.001
2	Arizona	0.991	56.2	0.056	2,680	13.18	1.12	1.18	1.09	0.09	2,304	0.051	0.047	0.004
3	Illinois	27.988	11.7	0.327	30,665	13.18	12.82	13.15	12.29	0.86	36,241	0.036	0.034	0.002
4	Indiana	16.017	6.05	0.097	22,229	13.18	9.29	9.39	8.84	0.55	23,729	0.040	0.037	0.003
5	Kentucky	49.716	7.47	0.371	58,688	13.27	24.70	25.07	23.39	1.68	17,318	0.145	0.135	0.010
6	Missouri	7.644	11.7	0.089	4,129	13.18	1.73	1.82	1.68	0.14	6,418	0.028	0.026	0.002
7	Montana	2.723	185.4	0.505	7,442	13.18	3.11	3.61	3.19	0.42	8,646	0.042	0.037	0.005
8	New Mexico	2.210	56.2	0.124	6,563	13.18	2.74	2.86	2.66	0.20	3,259	0.088	0.082	0.006
9	North Dakota	3.683	51.2	0.188	6,016	13.18	2.51	2.70	2.47	0.23	2,504	0.108	0.099	0.009
10	Ohio	35.208	7.47	0.263	31,477	13.27	13.25	15.88	12.58	3.3	55,994	0.028	0.022	0.006
11	Pennsylvania	43.455	7.47	0.324	24,318	13.27	10.23	10.55	9.78	0.77	57,406	0.018	0.017	0.001
12	Tennessee	7.624	11.7	0.089	4,893	13.27	2.06	2.15	1.98	0.17	12,990	0.017	0.015	0.002
13	Texas	1.942	89.0	0.172	3,670	13.18	1.53	1.70	1.54	0.16	17,419	0.009	0.008	0.001
14	Virginia	10.680	7.47	0.079	9,104	13.27	3.83	3.91	3.64	0.27	15,139	0.026	0.024	0.002
15	West Virginia	40.877	7.47	0.305	20,031	13.27	8.43	8.73	8.07	0.66	6,776	0.129	0.119	0.010
16	Wyoming	2.760	56.2	0.155	9,514	13.18	3.98	4.13	3.84	0.29	2,391	0.173	0.161	0.012
	Total				253,415		106.6	109.8	101.8	8.00				
	Other states				10,197		4.26	4.26	4.0	0.26				
	National				263,612		110.86	114.06	105.8	8.26	566,720[e]	0.019	0.018	0.001

[a] Blanks indicate data not applicable.

[b] Total respirable dust K = 1, $X_1 = 1.00$.

[c] Respirable coal dust K = 2, $X_2 = 0.927$.

[d] Respirable overburden dust, K = 3, $X_3 = 0.073$.

[e] Total national particulate emissions (all sources), g/s.

(59) 1972 National Emissions Report. EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 422 pp.

TABLE C-2. DISTRIBUTION OF COAL AND OVERBURDEN EMISSIONS

Unit operation/ source	National emissions, g/s	Estimate of dust, % coal	Coal emissions, g/s	Estimate of dust, % overburden	Overburden emissions, g/s
Drilling	13.28	50	6.64	50	6.64
Coal loading	16.37	100	16.37	0	0
Transport/ unloading	45.79	100	45.79	0	0
Blasting	34.67	100	34.67	0	0
Augering	0.7	100	0.7	0	0
Wind erosion	3.2	50	1.61	50	1.61
Total	114.1		105.8		8.2

Thus the weight percent of coal in the dust is 105.8/114.1 x 100 = 93%. This is a crude approximation, but it is indicative of the fact that coal dust is the major pollutant.

REPRESENTATIVE - MINE SIZE AND DISTANCE

Representative Size

Mine A disturbs 6.197×10^5 m^2/yr of land, per personal communication with mining personnel. This mine produces 835,531 metric tons per year at a 13.6 (m/m) stripping ratio. The land disturbance of any mine should be proportional to stripping ratio and tonnage; thus, for one year:

$$A_D = 5.45 \times 10^{-8} \; P \times S_R \qquad \text{(C-1)}$$

where A_D = annual land disturbance, km^2

P = annual tonnage, metric tons

S_R = stripping ratio, m/m

The average life expectancy of any strip mine is approximately 20 years (35). The average mining property size, A_P, is 20 times Equation C-1; thus,

$$A_P = 1.09 \times 10^{-6} \; P \times S_R \qquad \text{(C-2)}$$

The representative mine size is computed knowing P and S_R. The weighted average S_R for the United States is 16.82 as calculated from Reference 34 and the state coal production for 1972.

The average mine size is 108×10^3 metric tons per year computed by dividing the total 1972 U.S. surface production by the number of strip mines (2,225). Thus, using Equation C-2, $A_p = 2.0$ km^2.

Representative Distance

The mine area is assumed circular such that the radius is the representative distance. Thus,

$$r = \sqrt{\frac{A_p}{\pi}} = 0.792 \text{ km} = 792 \text{ m}$$

GLOSSARY

amorphous: Without stratification or other division; uncrystallized.

ANFO: Ammonium nitrate and fuel oil mixture used as an explosive.

anthracite: Hard compact natural coal containing only a small amount of volatile matter.

auger: Similar to a bit used for boring holes in wood the auger consists of a cutting head with screwlike extensions; the head breaks the coal and the extensions raise and dump it onto conveyors.

auger mining: Method of removing surface coal by boring holes into the coal bed using an auger.

azimuth: Horizontal direction expressed as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object.

bituminous: Soft coal containing considerable volatile matter.

confidence interval: Range over which the true mean of a population is expected to lie at a specific level of confidence.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

fibrosis: Growth of fibrous connective tissue in an organ in excess of that naturally present.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

growth factor: Ratio of 1978 emissions of respirable dust to 1972 emissions of respirable dust.

hazard factor: Primary ambient air quality standard (for criteria pollutants) or a reduced threshold limit value (for noncriteria pollutants).

lignite: Variety of coal intermediate between peat and bituminous containing much volatile matter; also called brown coal or wood coal.

noncriteria pollutant: Pollutant for which ambient air quality standards have not been established.

overburden: Loose soil, gravel, sand, or similar material overlying a deposit of useful geological materials (such as a coal seam).

pneumoconiosis: Disease of the lungs caused by habitual inhalations of irritant mineral or metallic particles.

precipitation-evaporation index: Reference used to compare the precipitation and temperature levels of various P-E regions of the U.S.

respirable particulates: Particulates with a geometric mean diameter less than or equal to 7 μm.

severity: Hazard potential of a representative source defined as the ratio of time-averaged maximum concentration to the hazard factor.

silicosis: Diffuse fibrosis of the lungs caused by the chronic inhalation of silica dust less than or equal to 10 μm in diameter.

stripping ratio: Ratio of the depth of overburden removed to depth of coal produced.

strip mining: Coal mining method by which overburden is removed coal is extracted in a series of regular slices, and the overburden is replaced.

subbituminous: Coal that is lower rank than bituminous but higher than lignite.

threshold limit value: Concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse affect.

tipple: Apparatus by which loaded cars are emptied by tipping sometimes including an elevated runway or framework upon which the cars are run for tipping.